NOTICE

All drawings located at the end of the document.

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KAISER - HILL
COMPANY

Work Plan
Site-Wide Water Balance
Rocky Flats Environment
Technology Site

August 15, 2000

Environmental Media Management

Rocky Flats Environmental Technology Site

Y68

Work Plan
Site-Wide Water Balance
Rocky Flats Environmental Technology Site

August 15, 2000

2

TABLE OF CONTENTS

3

TABLE OF CONTENTS (continued)

4

TABLE OF CONTENTS (continued)

LIST OF ACRONYMS

ac-ft/yr	acre-feet per year
AME	Actinide Migration Evaluation
ASI	Advanced Sciences, Inc.
BZ	Buffer Zone
CDPHE	Colorado Department of Public Health and Environment
DOE	Department of Energy
DQOs	data quality objectives
DWB	Denver Water Board
EG&G	EG&G, Inc. (formerly Edgerton, Germeshausen and Grier, Inc.)
ET	evapotranspiration
ft BGS	feet below ground surface
GW	groundwater
HELP	Hydrologic Evaluation of Landfill Performance (model code)
IA	Industrial Area
in/yr	inches per year
Kaiser-Hill	Kaiser-Hill Company, LLC
LHSU	Lower Hydrostratigraphic Unit
OU	Operable Unit
PARCC	precision, accuracy, representativeness, comparability, and completeness
PEST	parameter estimation (model code)
QA	quality assurance
PVC	polyvinyl chloride
RFA	Rocky Flats Alluvium
RFCA	Rocky Flats Cleanup Agreement
RFETS	Rocky Flats Environmental Technology Site
RMRS	Rocky Mountain Remediation Services LLC
SID	South Interceptor Ditch
sq. mi.	square mile
SW	surface water
SWWB	Site-Wide Water Balance
UHSU	Upper Hydrostratigraphic Unit
WBWG	Water Balance Working Group
WEPP	Water Erosion Prediction Project
WWE	Wright Water Engineers
WWTP	wastewater treatment plant

6

Executive Summary

The Rocky Flats Environmental Technology Site (RFETS or site), located 16 miles northwest of Denver, Colorado, encompasses approximately 6,500 acres, is owned by the Department of Energy (DOE), and is operated by Kaiser-Hill Company, LLC (Kaiser-Hill). Before its current closure mission, RFETS was part of the nationwide nuclear weapons research, development, and production complex. The site is currently undergoing aggressive cleanup with a goal for site closure by the end of 2006. As part of developing a detailed design basis for closure activities, RFETS is conducting a site-wide water balance (SWWB). The objective of the SWWB is to provide RFETS with a management tool to evaluate how the site-wide hydrology is likely to change from current to final site configuration.

This Work Plan outlines the water balance scope and schedule, presenting the preliminary conceptual hydrologic model for the site and the general modeling approach. The relevant data quality objectives (DQOs) for the project are provided in Appendix A.

The Work Scope (parts of which have been initiated or completed to facilitate preparation of this document) consists of:

- Task 1. Development of the Work Plan
- Task 2. Review of existing data
- Task 3. Initiation of the Water Balance (including model code selection, determination of model input parameters, and initiation of analysis and modeling)
- Task 4. Calibration of the Model
- Task 5. Analysis of Modeling scenarios
- Task 6. Preparation of the Modeling Report

The approach for each of these tasks, as detailed in this Work Plan, is summarized below.

<u>Review of Existing Data</u>
Data sources reviewed in the development if this Work Plan include:

- Thematic site characterization reports
- Area- or process-specific reports
- Modeling reports
- Historic and ongoing hydrologic and meteorological monitoring
- The RFETS database and geographic information system (GIS) repository
- RFETS Facilities Engineering drawings
- Individual SWWB team databases

These data sources are listed and summarized in Appendix B. Data evaluation will be an ongoing process throughout the course of the project.

7

An evaluation of existing data, according to type, location, format, and a preliminary assessment of the quality and available quantity, was performed and is summarized in a "data matrix" in Appendix C. In preparation of this matrix, data gaps were identified, and additional data collection was proposed to provide further constraint on the hydrologic system boundaries or internal processes. Additional site data collection activities for the SWWB project include:

- Compilation of data to quantify imported water flow
- Monitoring of in-situ treatment system outflows
- Monitoring of major footing drain outfalls as possible
- Collection of culvert data from the BZ and IA
- Collection of flow data from 6 additional surface water flow gauging locations
- Collection of flow data from the Broomfield McKay Bypass Pipeline monitoring system
- Monitoring of continuous groundwater levels at 12 additional sites
- Monitoring of quarterly groundwater level measurements at 73 additional sites

Initiation of the Water Balance

Initiation of the water balance modeling requires development of a conceptual model, based on the data review and problem formulation. The conceptual model is the basis for developing a numerical model to predict flow rates within the system. In preparation of this Work Plan, conceptual models were developed for the site, and for the IA. These conceptual models consider, and partially quantify, flow associated with the following processes:

- Precipitation in the BZ and IA from rainfall and snowmelt
- Ponding
- Overland flow
- Surface water flow in natural drainages and ditch systems
- Groundwater recharge
- Macropore flow
- Unsaturated zone flow
- Groundwater flow and variability
- Groundwater discharge and hillside seeps
- Evapotranspiration (potential and actual)
- Phreatophyte transpiration
- Pressurized pipe leakage
- Storm and sanitary sewer infiltration and exfiltration
- Foundation drains
- Utility corridors

Following conceptual model development, the solution approach is defined by selecting an appropriate engineering tool (modeling code), based on the model inputs and the complexity of the conceptual model. A physically-based, distributed-parameter, continuous-event integrated hydrologic model will be used to simulate the complex hydrologic site conditions. Physically-based model codes represent the most data-intensive type of hydrologic model that could be

8

applied to the SWWB, allowing for the incorporation of spatially varying parameters of the hydrologic system and modeling of the complex interaction between the surface and groundwater systems. Therefore, these codes were used to establish the baseline criteria for developing this work plan. Specific guidelines will also be applied to the code selection process. The selected code must:

- Be available in the public domain (non-proprietary).
- Be capable of handling the various types, quantity, and quality of available data, and the complexities of the conceptualized hydrologic system.
- Have distinct advantages over other existing codes.
- Meet specific standards, if they exist.

A separate *Model Code and Scenario Selection Report,* presenting the model code selection process and results in detail, will be issued after this Work Plan is formally approved.

Calibration of the Model

After model development, calibration of the site-wide and local-scale models will be performed. Calibration will be performed first for individual hydrologic processes like groundwater flow, surface water flow, etc., and then will be integrated for the complete hydrologic system. Due to the very large number of parameters influencing an integrated hydrologic system, the calibration process will not be automated, but will be performed manually.

The model calibration year is nominally calendar year 2000, which also represents current conditions against which future scenarios will be compared. Because model calibration will start before all the additional data for 2000 have been obtained, the calibration year will include data from most of the expanded 2000 monitoring program, and some of the preceding year's monitoring program. This is the best available data set, both in terms of data frequency and areal coverage, to constrain boundary conditions and the internal system response.

The calibrated model will also be checked against historic (1995-1999) data to evaluate and validate its overall performance, recognizing the effects of changes in surface water management protocols. Where appropriate, the model may be further calibrated to match specific events during these periods. Validation may also be performed against the complete 2000 data set as it becomes available.

Calibration will be followed by a sensitivity analysis, to identify and evaluate the model parameters that most significantly affect model outputs, such as potentiometric heads, surface water stage height or flows, etc.

Analysis of Modeling Scenarios

After the sensitivity analysis, a focused set of future closure simulation scenarios will be modeled. Scenarios included in the *Model Code and Scenario Selection Report* will reflect changes in site configuration due to closure under a range of climatic conditions.

A Monte Carlo-type uncertainty analysis will utilize results obtained during the sensitivity analysis and future scenarios to evaluate the uncertainty of model predictions to the range of uncertainty in model input parameters. Only the most sensitive parameters determined through the sensitivity analysis will be incorporated into the Monte-Carlo Method. The Latin-Hypercube Sampling method may be used to perform the Monte Carlo simulations, as it offers a more computationally efficient approach compared to standard Monte Carlo Methods.

Preparation of Modeling Report

After completion of the modeling, results will be presented in a Modeling Report, using appropriate formats to facilitate communication with the various stakeholders on issues relating to on-site water management. The report will include: objectives and purpose of the SWWB; description of the model; model calibration results; sensitivity analysis results; future scenario results; uncertainty analysis results; and quality assurance.

1.0 Introduction

The Rocky Flats Environmental Technology Site (RFETS or site) is located 16 miles northwest of Denver, Colorado, in Jefferson County. The site, shown on Figure 1-1, encompasses approximately 6,500 acres, is owned by the Department of Energy (DOE), and is operated by Kaiser-Hill Company, LLC (Kaiser-Hill). Before its current closure mission, RFETS was part of the nationwide nuclear weapons research, development, and production complex. The site consists of two distinct areas: (1) the Industrial Area (IA), and (2) the Buffer Zone (BZ). The major plant facilities, including all production buildings and infrastructure, are located within the centralized, 400-acre IA. The BZ is a 6,150-acre area surrounding the IA. The BZ is mainly open grassland, but it also includes the access roads, clay and gravel mine pits, two landfills, the water supply pond, much of the Building 130 complex, the South Interceptor Ditch (SID), the Western Diversion, the A, B, and C series ponds, and several irrigation ditches.

The site is currently undergoing aggressive cleanup with a goal for site closure by the end of 2006[1]. As part of developing a detailed design basis for closure activities, RFETS is conducting a site-wide water balance (SWWB). The SWWB will be based primarily on results obtained using a physically based, integrated hydrologic model. This effort will be supported, where appropriate, with additional analysis that may involve coupling simpler hydrologic component models. The Water Balance Working Group (WBWG), consisting of on-site specialists in groundwater and surface water hydrology, and an outside subcontractor providing hydrologic modeling support, will conduct the SWWB.

This Work Plan describes the conceptual hydrologic model for the site and outlines the water balance scope, the schedule, the model(s) selection process, the potential data needs, and the anticipated results. The relevant data quality objectives (DQOs) for the project are provided in Appendix A.

The purpose of the Work Plan is presented in Section 1.1, followed by a definition of the SWWB study area in Section 1.2. Data and reports obtained and reviewed by the WBWG for use in developing this Work Plan are summarized in Section 1.3. A flow chart outlining the overall approach for the SWWB is presented in Section 1.4. A conceptual hydrologic model was developed for this work plan based on the review of existing data. This conceptual model, and the approximate extent and location of the boundaries for the SWWB model, are described in Section 2.0. Section 3.0 presents the detailed Scope of Work for the SWWB. The process for selecting the appropriate model code(s) is discussed in Section 3.3.

This work plan does not assume that a particular modeling code will be used. However, the proposed conceptual model requires that a physically-based, distributed parameter, continuous-event simulation model to meet the objectives of the SWWB. Physically based codes represent the most data-intensive type of hydrologic model that could be applied to the SWWB, allowing for the incorporation of spatially varying parameters of the hydrologic system and modeling of the complex interaction between the surface and groundwater systems. Making this assumption

[1] In this work plan, references to a year are for the calendar year, unless otherwise indicated.

11

ensures that any code (or combination of codes) ultimately selected for the SWWB will be valid for this work plan. Based on the actual model selection process (Section 3.3), and preliminary testing of the selected model code(s), the simplest model that can be used without significantly compromising the modeling objectives will be adopted. In short, the specific tasks and their interrelationships (shown in the flow-chart approach described in Section 1.4) are considered valid for any model code, or combination of model codes, selected for use in the SWWB.

1.1 Purpose

The purpose of this work plan is to provide the framework for conducting the SWWB modeling for the site. Closure activities and the final end-state configuration have the potential to significantly alter groundwater, surface water, and near-surface flow at the site. Further, many site closure decisions cannot be made without first considering quantified predictions of effects on groundwater and surface water flow.

The objective of the SWWB is to provide RFETS with a management tool to evaluate how the site-wide hydrology is likely to change from current to final site configuration (current indicates 2000 site configuration). SWWB results may serve to provide information for final IA configuration to protect surface water quality (e.g., excavation, backfill, cover design, and land recontouring), and support preparation of the comprehensive risk assessment and RFETS Corrective Action Decision/Record of Decision.

Ultimately, this tool may also be applied as part of future RFETS projects, such as prediction of surface water impacts from groundwater for present and final site configuration, and provision of information to support the final configurations of the Walnut Creek and Woman Creek drainages.

1.2 Study area

The SWWB study area is defined as the extents of the RFETS property boundary, shown on Figure 1-1. The study area extends from Highway 93 at the western boundary to Indiana Street at the eastern boundary, and from Highway 128 at the northern boundary to the fenced southern boundary (approximately 3 miles away). The SWWB model boundary is contained within the study area and is described in more detail in Section 2.0.

Three drainage basins - from north to south: Rock, Walnut, and Woman Creeks - convey surface water at the site (Figure 1-1). Drainage within these basins, excluding the IA, is mainly by natural ephemeral and perennial streams that generally flow from west to east. The northwest part of the study area is drained by Rock Creek, which flows into Coal Creek northeast of the site. The Rock Creek drainage is believed to be unaffected by site activities and will not be included in the SWWB. Therefore, the SWWB modeling will focus on the Walnut and Woman Creek drainages and the associated upgradient groundwater source areas within the site property boundary.

13

1.3 Data review and analysis

The data and report review task is described in Section 3.2. This task is expected to progress throughout the SWWB project, due to continuing collection of data for the project; however, most of the existing and available data and reports were reviewed by the date of this Work Plan. This section briefly summarizes results of the data review that were used to develop the conceptual hydrologic model of the site (see Section 2.0) and this Work Plan (see Task 1, Section 3.1). Information from site reports, together with ongoing hydrologic and meteorological monitoring, will ultimately be used to support development of the numerical flow model for the SWWB.

Principal sources of data and reports obtained and reviewed include:

- RFETS database and geographic information system (GIS) repository
- RFETS Facilities Engineering drawings
- Various RFETS reports (listed in Appendix B)
- Individual SWWB team databases:
    - Surface Water Group
    - Groundwater Group
    - Meteorology Group
    - Ecology Group
    - DOE Closure Group

Data were evaluated based on their source, quality, quantity, and type. The latter three factors can represent the most significant limitation in developing a successful and detailed water balance for the site. To aid in this evaluation, the existing data have been summarized in a "data matrix", presented in Appendix C. For each data type, the location, format, and a preliminary assessment of the quality and available quantity are presented. The data matrix is useful in organizing the substantial amount of available data and identifying gaps in the data. Identification of data gaps has resulted in the proposed collection of additional site data for the SWWB modeling work (see Section 3.2).

Appendix B summarizes the reports reviewed for the SWWB work, including available reports related to past and present modeling studies. Several modeling studies have been conducted at RFETS. These have focused on individual hydrologic processes, or on a particular Operable Unit (OU). Other relevant reports reviewed included geologic and hydrogeologic characterization reports, OU investigations, and the Zero Site Discharge Investigations. These reports included data and interpretations useful for the SWWB. The report review summary, presented in Appendix B, includes, for each report, a brief summary and conclusions, identification of data and assumptions used in the report interpretations, and notation of model inputs and parameters that could be used in the current SWWB project.

14

Based on the data review and conceptual model development, the WBWG has identified additional data to be obtained in 2000 to support the SWWB. The additional data to be collected will include the following:

- Additional surface water flow gauge sites
- Additional continuous groundwater level monitoring sites
- Additional quarterly groundwater level measurements

Locations of additional data collection sites are shown in Figure 1-2. Additional data collection activities are presented in detail in Section 3.2.

1.4 General modeling approach

Figure 1-3 presents a flow chart outlining the general modeling approach that will be used for the SWWB. The problem formulation is driven by the project objectives specified in Section 1.1, although the available data and management and engineering considerations also constrain the SWWB approach, as shown in Figure 1-3. It is important to note that engineering constraints, such as the limitations of numerical flow models to simulate heterogeneous and complex hydrologic flow processes, lack of data, data measurement errors, and final design considerations, all play significant roles in developing the approach for completing the SWWB.

A conceptual hydrologic model of the entire RFETS hydrologic system has been developed based on a review of the data and the problem formulation. This conceptual model serves as the basis for development of a numerical model used to predict flow rates within the system. Consequently, the success of a numerical model is generally highly dependent on how well the conceptual model is formulated. A 3-dimensional conceptual hydrologic model of the RFETS site is presented in Section 3.0.

Following development of the conceptual model, a solution approach is defined by selecting an appropriate engineering tool, based on the model inputs (i.e., type, quantity, and quality of available data) and the complexity of the flow system (conceptual model). Based on the data and report review (Section 1.3), and the conceptualization of flow in the system, it is apparent that the integrated hydrologic system is complex and depends on a number of factors. Many numerical codes exist that could simulate many of the processes outlined in the conceptual hydrologic model. However, only a few are capable of addressing all the relevant hydrologic process components simultaneously. Even fewer codes are capable of considering many of the conceptual hydrologic model components at appropriate resolutions required by the modeling objectives. Details of the model code selection process are presented in Section 3.3.

It was assumed that a fully integrated, physically-based, continuous, distributed-parameter, numerical modeling code (Storm and Refsgaard, 1996) will be selected for SWWB work. This represents the most data-intensive type of code that could be selected for performing the SWWB, but offers the greatest potential for meeting all project objectives. In an integrated model, surface water, unsaturated zone, and groundwater flow are simultaneously solved,

THIS TARGET SHEET REPRESENTS AN OVER-SIZED MAP / PLATE FOR THIS DOCUMENT

Work Plan Site Wide Water Balance Rocky Flats Environmental Technology Site

Proposed Additional Monitoring
Location Figure 1-2

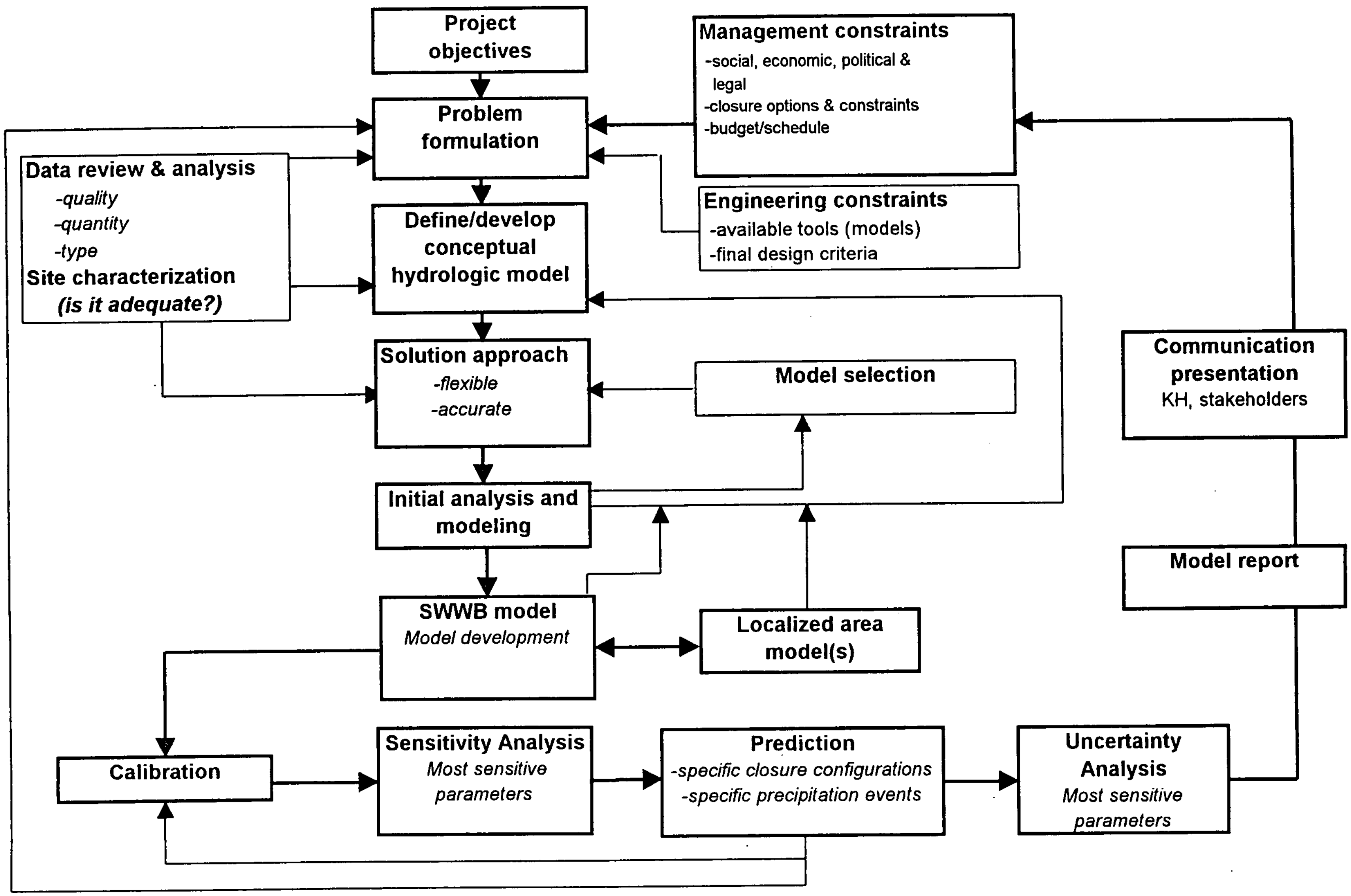
CERCLA Administrative Record document, SW - A - 004099

U.S. DEPARTEMENT OF ENERGY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE

GOLDEN, COLORADO

16

Figure 1-3
Site-Wide Water Balance general modeling approach



17

allowing all state variables of the system (e.g., groundwater potentiometric head, stream stage height, etc.) to be determined spatially and temporally. Although it is possible to develop separate models for the surface water and groundwater systems, an integrated model also ensures consistency among the water balance components. For example, the variable groundwater recharge rates and soil moisture conditions determined from an integrated model that includes a physically based vadose zone component ensure that the flow rate between surface and groundwater is physically realistic and that mass is conserved between the surface water and groundwater components. Estimated recharge rates can be more readily justified, especially if the model is calibrated using both surface and subsurface data, including groundwater levels, soil moisture, baseflows, or the extent of saturated areas. An integrated model, based on a more comprehensive conceptual hydrologic model of the site, provides a better tool for predicting the changes that are likely to ensue from various closure and water management options.

As illustrated on Figure 1-3, initial analysis and modeling will be performed before development of the SWWB model. This will allow for updating and refinement of the current conceptual hydrologic model of the RFETS system, and better definition of the sensitivity of results to the various input parameters and conceptual hydrologic model formulations. It is anticipated that the initial analysis will include spatial and temporal analysis of precipitation, analysis and modeling of vadose zone processes and groundwater recharge, and analysis and modeling of the IA groundwater balance. The initial analysis and modeling may also include development of a simplified, fully-integrated model of the site. The purpose of the initial simplified integrated model is to determine an appropriate grid resolution, and to establish the sensitivity of the integrated hydrologic system to various model input parameters and various refinements of the geologic model. Results of the simulations using the simplified integrated model will feed back into the model selection, as shown in Figure 1-3.

The site-wide model, incorporating all of the factors considered significant to meeting the SWWB objectives, will be developed following initial analysis and code selection. The site-wide model will either be fully integrated or loosely coupled. It will provide the appropriate resolution for the entire model area. However, the need to develop a computationally efficient numerical tool may prevent specifying a grid resolution within localized areas, such as the IA, that is fine enough to adequately simulate the effects of features like specific footing drains, impervious areas, or subsurface piping on the hydrologic system. A coarser grid in this area (100 to 200 feet) will effectively lump the effects of these features into a single model cell. It should be noted that the effects of these features on the hydrologic system may not be clear based on existing data and interpretation (e.g., potentiometric surfaces). Consequently, spatial averaging of these features within larger model cells may be justified as the most appropriate technique. These differences in the scale appropriate for modeling the hydrologic processes will be addressed in more detail after performing initial simulations with the selected code.

The general modeling approach, presented in Figure 1-3, also includes localized area modeling, such as a local-scale hydrologic model for the IA. A local IA model will be developed if, based on results of either the initial IA modeling analysis or the initial site-wide integrated modeling, it is determined that the grid resolution of the final site-wide model is too coarse to simulate

18

important features within the IA to adequately meet project objectives. The local-scale model facilitates modeling the unique hydrologic components of the IA (pipe leakage, sewer infiltration/exfiltration, building drains, impervious surfaces, pipe flow, etc.) that require greater spatial resolution and special calibration treatment. The site-wide model would provide the boundary conditions for the local-scale model in order to provide continuity between the two models. Details of the development of these two models are discussed further in Section 3.3.

Calibration of the site-wide and local-scale models will follow their development; this is discussed in Section 3.4. A sensitivity analysis will be performed following model calibration. This is an important step in identifying and evaluating those model parameters that most significantly affect specified model output variables (i.e., system heads, surface water stage height or flows, etc.). Section 3.5 describes the predicted future closure simulation scenarios that will be performed after the sensitivity analysis. Section 3.7 describes the uncertainty analysis that will be performed after simulating the future closure scenarios. The uncertainty analysis will utilize results obtained during the sensitivity analysis and future scenarios to evaluate the uncertainty of model predictions (on model output variables) to the range of uncertainty in model input parameters.

After completion of the modeling, results will be presented in a Modeling Report, using text, spatial, and graphical formats to facilitate communication with the various stakeholders on issues relating to onsite water management. Details of the Modeling Report are presented in Section 3.6.

2.0 Model boundary and conceptual hydrologic model

The locations of model boundaries, and the conceptual model of hydrologic components and processes, are very closely interrelated. Therefore, they are considered together in this section. A well-defined conceptual hydrologic model, based on data and fundamental hydrologic principles, is critical to developing a numerical hydrologic model capable of providing reliable predictions. The conceptual hydrologic model must define all relevant hydrologic components and processes. "Relevant components" are those features that influence the hydrologic and hydraulic flow system within the RFETS model area, including external and internal boundaries (e.g. ponds, pipe interaction, etc.). "Processes" are the physical hydrologic processes, such as precipitation, evapotranspiration, unsaturated flow, groundwater flow, and surface flow. Development of a consistent and comprehensive conceptual model is an important task for the RFETS system because the system is complex, both spatially and temporally. It is further complicated by the man-made factors that are known to significantly influence various components of the site-wide water balance.

The conceptual model presented in this work plan will be revised throughout the SWWB project. Although most of the significant hydrologic components have been readily identified, many of the hydrologic processes can only be loosely conceptualized at this point based on available data and existing characterization. Therefore, the integrated hydrologic system can only generally be conceptualized at this point. It is important to realize that the conceptual model defined here is not final, and that it will be revised (as described in Section 1.4) through simulations performed using the coarse grid, site-wide, or local-scale models. It is expected that, through modeling and continual redevelopment of the conceptual model, a much better understanding of how the system operates under a variety of stresses or modifications (i.e., closure) will be attained.

System flow conceptualization will occur after data have been collected, synthesized, and analyzed. Both the hydrogeologic and geologic characterization studies (EG&G, 1995a and EG&G 1995b, respectively) are used as the primary basis for developing the present conceptual model. These reports are quite comprehensive in their characterization of the hydrologic system at RFETS. These reports specifically address the hydrogeology and the geology of the site, including definition of hydrostratigraphic units, the occurrence and distribution of groundwater, groundwater recharge and discharge, hydraulic properties, groundwater geochemistry, and surface water/groundwater interactions. The conceptual model presented here does not repeat the detail in these reports, but instead focuses on identifying the key components of the conceptual hydrologic model that will be considered in the SWWB.

Previous studies and reports have provided a thorough and detailed characterization of hydrologic, geologic, and water quality conditions at RFETS. However, the previous reports and studies have not provided an integrated conceptual hydrologic model for RFETS, including surface flow, unsaturated zone flow, groundwater flow, and their interactions over the entire site. The comprehensive conceptual model will address the complexities associated with the IA and provide estimates of mass fluxes associated with each component or process. Conceptualization of the hydrologic flow system within the IA is difficult because of its

20

complexity, and is further complicated by incomplete or inconsistent as-built drawings, limited information on building drain flows and routing paths, and insufficient information to satisfactorily quantify the magnitudes of pressurized pipe leakage and sewer infiltration/exfiltration.

A model boundary and general conceptual hydrologic model of the entire RFETS for the SWWB are presented below. The conceptual hydrologic model forms the basis for development of the integrated, physically based, numerical model of the system. The conceptual hydrologic model provides a description of boundary conditions, flow paths, and component processes. It also provides a common platform from which all reviewers of the SWWB can evaluate the general modeling approach and better understand how the system will be modeled. The primary hydrologic processes and components are described for both the BZ and IA for current conditions. An initial conceptual model is also described for site-wide closure (2006), although it should be noted that not all details of site-wide closure have yet been finalized.

Several generalized drawings are used to illustrate the important hydrologic components and physical processes to be considered in the SWWB. Numerical modeling will provide a better understanding of how the system operates and will permit identification of the most sensitive parameters.

2.1 Model boundaries

The model boundaries were defined based on initial conceptualization of the flow system. Early definition of the model boundary eliminated the need to obtain and evaluate data outside of the boundary. Additionally, early definition allowed for identification of additional data needs, principally along parts of the boundaries where insufficient data existed.

The horizontal model boundaries (Figure 2-1) encompass an area of approximately 3,700 acres (~5.8 sq. mi.). These boundaries are valid for both surface and subsurface flows.

The vertical (upper and lower) boundary conditions for the SWWB model are the topographic surface and the contact between the weathered and unweathered bedrock, respectively. The topographic surface is the obvious boundary between groundwater and surface water. The bottom boundary is similar to that used in earlier modeling efforts (Roberts, 1997; US DOE, 1995; and EG&G, 1995c). Furthermore, it is consistent with definition of the Upper Hydrostratigraphic Unit (UHSU) definition described in the Hydrogeologic Characterization Report (EG&G, 1995a). The rationale for the lower boundary selection is that the unweathered bedrock or Lower Hydrostratigraphic Unit (LHSU) transmits a negligible amount of flow compared to the UHSU (EG&G, 1995a).

Lateral boundary conditions take into account both surface and groundwater. However, more weight was given to surface water boundaries, because the numerical model will likely be much more sensitive to surface water flows than groundwater flows (that is, surface water will exhibit greater flows and faster response times than groundwater, for the same area).

21

The western boundary extends about 1 mile from north to south, in three separate segments. The boundary follows the RFETS western property boundary for 0.65 miles south of the West Access Road, 0.33 miles along the West Access Road, and 0.33 miles north of the West Access Road (see Figure 2-1). From this point it extends northward, roughly parallel to the groundwater potentiometric contour lines. This boundary is just east of the Laramie-Fox Hills aquifer outcrop. Specifying the boundary at this location, rather than further west, avoids having to simulate losses to the Laramie-Fox Hills aquifer system. Furthermore, the western boundary appears to have adequate continuously monitored surface and subsurface data. As a result, current up-gradient mining and water management operations will not be simulated in detail in the model, but their influence will be represented be the boundary condition, based on observed groundwater levels, applied at the western boundary. Though not a problem for simulating current conditions (because current monitoring data are adequate), simulating future conditions may require specification of a time-varying boundary condition that will reflect such potential up-gradient influences.

Currently, groundwater and surface water are both assumed to flow into the model along the entire western boundary. Very little overland flow is expected to flow across either the southern or northern segments of the western boundary, because of the relatively low topographic gradient. However, it is possible that some overland flow occurs across the southern portion of the western boundary, due to flood irrigation on the McKay property just west of the RFETS property boundary. This would only occur during summer months, and is more likely to occur along the surface drainage features, which will be continuously monitored, so that the additional component could be (at least roughly) estimated. Channelized flow occurs in the Woman Creek drainage and in the Upper Church and McKay Ditches, all of which are continuously monitored. Although the groundwater table configuration will vary in response to direct recharge and lateral inflow, the groundwater flow direction is expected to remain relatively unchanged throughout a year.

Flow within the McKay and Upper Church Ditches typically occurs only during spring or summer months. Notable losses to the groundwater occur, as a result of these ditches being unlined (Wright Water Engineers [WWE], 1995). Therefore, along this part of the western boundary, it is expected that both surface water and groundwater flows will respond directly to flow events in these ditches.

The eastern boundary is defined as the eastern RFETS boundary (Indiana Street). This boundary extends approximately 2.3 miles from north to south. The principal drainages across this boundary are Woman and Walnut Creeks. Minor drainage features also cross this boundary (i.e., Mower Ditch, Badger Ditch, Kestrel Gulch, and three other unnamed features). Each minor drainage feature is culverted beneath Indiana Street. Topographic modifications redirect surface water flows along Indiana Street between these culverts and act to drain overland flow accumulations. Flows along the minor drainages are generally negligible year round except during significant precipitation or snowmelt events. No overland flow crosses Indiana Street.

23

Groundwater flow across the eastern boundary is specified based on continuous groundwater monitoring data. Most of the groundwater flow at the eastern boundary is within the alluvium of Walnut and Woman Creeks. The groundwater flow across the boundary between Walnut and Woman Creek originates from direct precipitation recharge within the area east of the IA and between the two creeks. The total groundwater flow across the eastern boundary is very low compared to surface flow and therefore, is not as critical in simulating the total flow across this boundary.

The north and south boundaries of the model are generally defined based on surface water divides, which are for the most part coincident with topographic divides (highs). The northern boundary will be specified as a no-flow surface water boundary, and a specified head type boundary for groundwater flow. The groundwater flow boundary has been specified as constant head in previous modeling efforts in approximately the same location (Roberts, 1997; CDPHE, 1994). However, since the SWWB will be simulating time-varying conditions, the northern groundwater boundary may experience a gradient change in this location due to flows in the McKay Bypass Ditch during the months when this water right is exercised. Therefore, this boundary will likely be specified as a time-varying head boundary condition based on nearby continuously monitored groundwater head data.

The southern model boundary is a no-flow boundary condition for both surface and groundwater. South Woman Creek normally does not receive flow from the Smart Ditch (see Figure 2-1), but at moderate to high flow rates, some flow from Smart Ditch can bypass the diversion structure used to prevent flow from Smart Ditch from entering South Woman Creek. However, according the RFETS surface water group, this location, and another location downstream on Smart Ditch, are not expected to contribute significantly to the annual surface water flows recorded at GS01, on Woman Creek, which receives surface flow from South Woman Creek. Therefore, the southern boundary was defined to include overland flow contributions to South Woman Creek, but not from the Smart Ditch. The southern boundary is defined similarly by the Water Erosion Prediction Project (WEPP, 2000).

2.2 Conceptual hydrologic model

The following sections provide a more quantitative understanding of the SWWB fluxes, i.e., volumes associated with specific components and processes. However, these are only approximate, and are limited to the extent that data or specific references are available to support these estimates.

2.2.1 Site-wide conceptual hydrologic model

Precipitation

Precipitation within the model area varies spatially for most storm events, despite its relatively small area (3,700 acres). Using the average annual precipitation of 15.5 inches, approximately

4,800 acre-feet per year (ac-ft/yr) of precipitation falls within the model area. Based on the reported annual range of precipitation at the site (6.6 to 22.5 in/yr), this volume can range from 2,000 to 7,000 ac-ft/yr. Seasonally, the greatest percentage of precipitation occurs during the months of April and May. Approximately 30 to 40% of the average annual precipitation occurs as snowfall. The distinction between rainfall and snowfall precipitation events is significant because snow occurs during periods of low evapotranspiration and its normally slow rate of melting enhances infiltration and reduces surface runoff. Both of these conditions enhance groundwater recharge relative to surface runoff. Accordingly, the spatial distribution of groundwater recharge varies according to slope, aspect, and elevation, although elevation changes across the model area are not a significant factor at the site.

Surface water flow

Figure 2-2 shows the principal surface hydrologic components that will be considered in the SWWB modeling. All surface flow occurs either as overland flow (i.e., sheet flow), or as channelized flow (i.e., drainages). The primary drainages within the model boundary are Walnut and Woman Creeks. Both creeks flow from west to east and have tributary sources that enter these Creeks before they reach the eastern model boundary and flow through culverts beneath Indiana Street. The smaller streams feeding into these creeks are not shown on Figure 2-2, but they will be considered in the SWWB, where significant. Woman Creek originates to the west of the western edge of the model boundary. A small part of the Walnut Creek drainage originates to the west of the western edge of the model boundary, but Walnut Creek also receives some flows from Upper Church and McKay Ditches, depending on the configuration of the diversion structure located on it. Also, a part of the Walnut Creek channel has been diverted due to development of the IA and landfills.

Surface water inflow across the model boundary occurs through Woman Creek, Owl Branch, and Upper Church and McKay Ditches. Based on surface water gauge data from 1993 through 1999, upstream annual estimates of flow into the model boundary along Woman Creek and Owl Branch (which feeds into Woman Creek) range from 50 to 233 ac-ft/yr and from 6 to 135 ac-ft/yr, respectively. For any month, daily flows can decrease to zero for consecutive days, though every month registers some flow, with the high-precipitation months of April and May recording the highest average flows. Other inflows along the western boundary occur along the Upper Church and McKay ditches. Reported estimates (Wright Water Engineers, 1995) indicate that these flows only occur during summer months, at rates greater than 900 ac-ft/yr. Though not previously monitored, it is believed these ditches lose water through seepage to groundwater, based on the field observations of the WBWG and Wright Water Engineers (1995). Losses due to seepage will be estimated as part of the SWWB project.

Surface discharge from the model boundary occurs only across the eastern boundary, principally through Walnut and Woman Creeks. Additional surface water discharge will be measured at the Broomfield Meter, which will record water purchased by Broomfield for the Great Western Reservoir. Surface discharge estimates based on existing gauge data from 1993 to present (at gauge stations GS01, GS02, and GS03) indicate that annual discharges at

25

Walnut Creek range from about 265 to over 1,500 ac-ft/yr, and annual discharges at Woman Creek range from about 70 to nearly 600 ac-ft/yr (including Mower Ditch flow). The higher ends of these ranges reflect the extreme precipitation events in 1995. Excluding the unusual conditions in 1995, Walnut Creek averages about 486 ac-ft/yr, and Woman Creek averages about 124 ac-ft/yr. The greater annual flows from Walnut Creek are due in part to its greater drainage area of approximately 5.5 sq. mi. (ASI, 1990), compared to a drainage area of approximately 3.0 sq. mi. for Woman Creek. Also, a significant portion of the flow from Walnut Creek is due to IA runoff, which is enhanced due to pavement cover. Walnut Creek discharges via the A and B pond series, which receive discharge from the wastewater treatment plant (WWTP). Thus, IA runoff and the A and B pond series discharges also contribute to the higher average annual flows on Walnut Creek compared to Woman Creek.

Within the model boundary, both Walnut Creek (EG&G, 1995a) and Woman Creek (Fedors and Warner, 1993) exhibit losing and gaining reaches that vary in reach length and flow rates throughout the year. The detailed Woman Creek study identifies and quantifies gaining and losing reaches, but it covers only a limited portion of the stream channel within the model boundaries. Expected controls on the gaining and losing reaches along surface drainage features include the saturated hydraulic conductivity of drainage sediments, the surrounding groundwater table, precipitation duration and intensity, drainage slope and cross-sectional geometry, and vegetation.

Overland flow occurs when water accumulates or ponds on the surface during precipitation events. Overland flow will not occur unless a single precipitation event, or a series of events, occur that feature volumes and/or intensities that are sufficiently large to exceed infiltration capacities of the surface and cause ponding. No site-wide estimates of overland flow contributions to surface flow for given precipitation events were available. Factors expected to control the overland flow include surface slope, aspect, microtopography, vegetation, soil types, infiltration capacity, and precipitation intensity and duration. Overland flow is expected to be greater on steeper slopes than for flat slopes, particularly where soils are less permeable and hence more prone to ponding water.

Ponds (see Figures 1-1, 2-1, and 2-2) are used to control runoff within the model area. These ponds are a significant factor in the SWWB because they provide storage capacity, variable surface water routing, and present open water surfaces available for evaporation. Initial estimates of evaporation, based on daily pond levels, daily inflow rates, and monthly evaporation rates (RMRS, 1999), indicate that roughly 70 ac-ft/yr may be evaporated from these ponds. Ponds also cause subsurface flow within stream alluvium to "daylight" as surface water. There have been significant changes in pond operations in the past, which will be taken into account in interpretation of historic data. For example, in the past operations moved water between and within drainages. Currently, Ponds A-3, A-4, B-3, B-5, and C-2 are managed by transfers and discharges using pumping systems or existing outlet structures. The remaining ponds have various routing options, but typically serve only to store water from local runoff without active management. Both North and South Walnut Creeks and the SID receive runoff from the IA, with pond B-3 receiving discharge directly from the WWTP.

21

Groundwater flow

Groundwater enters the model boundary only through the western model boundary within the upper hydrostratigraphic unit, mainly within unconsolidated material, but with some flow occurring in weathered bedrock. Figure 2-3 shows a generalized cross-section along the principal groundwater flow direction, from west to east. Both the saturated thickness and the saturated hydraulic conductivity of the RFA generally decrease from west to east (EG&G, 1995a). This effectively decreases the transmissivity and flow rate from west to east within this unit. In plan view, the groundwater flow also appears to diverge from west to east as a result of the increase in watershed catchment width for Walnut and Woman Creeks from north to south. Estimates of average annual inflow along the western model boundary range from about 32 to 53 ac-ft/yr.

Groundwater flow is strongly influenced by topography across the model area because the underlying bedrock surface closely mimics the surface topography and the saturated thickness is small in comparison to the change in elevation.

Groundwater recharge/unsaturated zone flow

According to the hydrogeologic characterization report (EG&G, 1995a), the system can be roughly divided into three principal recharge areas, western, central, and eastern. The highest recharge area is associated with the RFA, which occurs mainly in the western, flatter area. The RFA is more gravelly and sandy than surficial deposits in the central and eastern areas. The flatter terrain favors higher recharge by direct infiltration, due to lower runoff.

The central area is characterized by a transition from the RFA to the lower permeability Laramie and Arapahoe Formation claystone/siltstones. It is also characterized by the occurrence of steep slopes that promote runoff and groundwater seepage to the surface, locally steepened in areas of landslide slumps (see Figure 2-3). The central area is an area of relatively low groundwater recharge. The eastern area is characterized by relatively flat surface topography, more common occurrence of higher-permeability valley fill material (compared to RFA) along drainages, and occurrence of lower permeability colluvium material outside of the drainages.

The eastern area is not considered an area of significant recharge because of lower vertical hydraulic conductivities, although vertical hydraulic gradients are mostly downward throughout this area.

Outside of the IA, the groundwater system is recharged primarily through precipitation, and secondarily by losing reaches of surface drainages (OU2 Report, DOE, 1995) and seepage from ponds and ditches. A comparison of continuous stream flow measurements with continuous water level measurements in nearby wells are shown in Figures 2-4, 2-5, and 2-6, for surface water gauges GS40, SW093, and GS34, respectively[2]. Well 05293, located near

[2] Locations of measurement points for Figures 2-4, 2-5, and 2-6 are shown in Figure 2-9.

28

stream gauge GS40, shows a recharge response to precipitation and runoff during the spring, but no recharge response to precipitation events and stream flows occurring during the remainder of the year (Figure 2-4). Well B210489, located near stream gauge SW093, shows a significant recharge response to precipitation and runoff during the spring, and a slight recharge response to runoff producing precipitation events occurring at other times of the year (Figure 2-5). On the other hand, Figure 2-6 shows that the streamflows at GS34 and the groundwater levels in nearby well 10794 do not fluctuate with season or precipitation. Instead, the response is due almost entirely to the regulated release from the A and B series ponds located upstream of these monitoring points. This pattern of behavior occurs only on the parts of Walnut Creek located downstream of the controlled-release ponds.

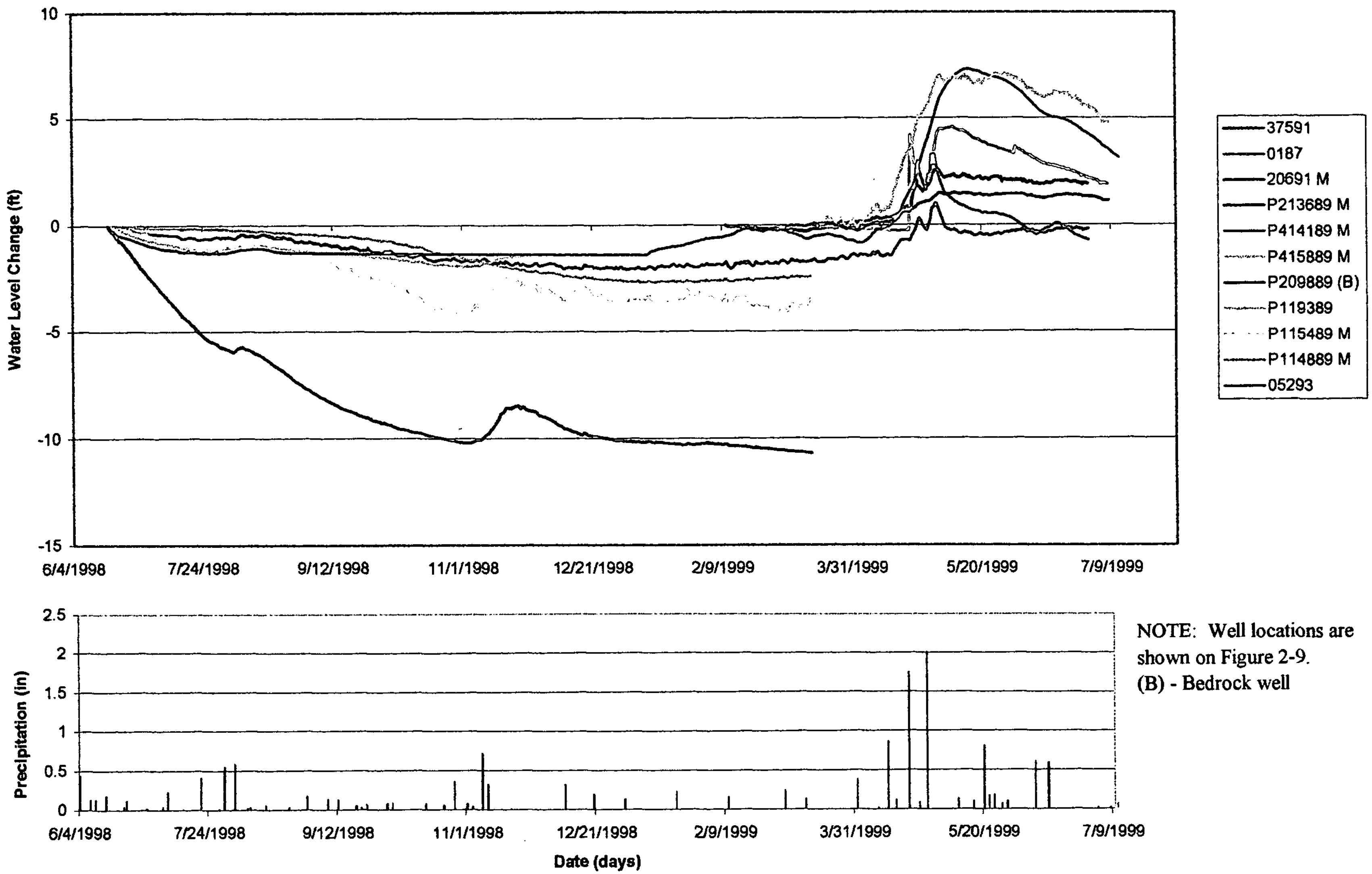
In the Rocky Flats Cleanup Agreement (RFCA) 1998 Annual Groundwater Monitoring Report (RMRS, 1999), continuous groundwater levels at a number of IA and BZ wells were compared against continuous precipitation data. These graphs have been updated with data from 1999, and are summarized in Figures 2-7 and 2-8, for the IA and BZ, respectively. Water levels at almost all of these wells decrease from a high that is likely associated with spring precipitation events, regardless of whether the well is screened within weathered bedrock or surficial deposits. Furthermore, water levels in most of these wells appear to respond to precipitation events relatively rapidly (i.e., within less than a week). This further suggests that groundwater in this area is recharged principally by direct areal precipitation.

The process of direct recharge by precipitation involves unsaturated zone flow processes. These processes are complicated and dependent upon a number of factors that are only partially known at the site. Factors influencing flow through the unsaturated zone include: precipitation intensity and duration, unsaturated soil hydraulic properties (residual and saturated moisture content, retention curve data, and saturated hydraulic conductivity), groundwater depth, changes in lithology, presence of macropores, surface microtopography, and climatic data (e.g., solar radiation, wind speed, relative humidity, etc.). Unsaturated zone flow is highly non-linear due to the variation in relative permeability with moisture content, and is complicated by the effects of vegetation, which extract water as a function of depth. Evapotranspirative losses can also be significant, particularly where vapor transport dominates. Unsaturated zone flows can also be significantly affected by air entrapment, causing hysteresis. That is, the hydraulic conductivity for a particular percent saturation is different in a wetting cycle compared with a drying cycle. These details of unsaturated zone flow processes are not well understood at RFETS.

Estimates of recharge are 0.01 to 3.0 in/yr in the most recent groundwater modeling report for the site (Roberts, 1997), 1.6 to 2.2 in/yr in the OU2 area modeling report (DOE, 1995), and 0.5 in/yr in the 881 Hillside modeling, for a location that is mainly colluvium/valley fill alluvium (Fedors et al, 1993). These estimates of recharge are relatively high as a percentage of precipitation for arid/semi-arid environments (Simmers, 1997). Fedors et al (1993) demonstrated that the vertical hydraulic conductivity of RFA was orders of magnitude higher in field tests compared with core samples, suggesting that recharge may be enhanced due to macropore flow. It may also be enhanced due to microtopography effects (ponding and snow drifting).

33

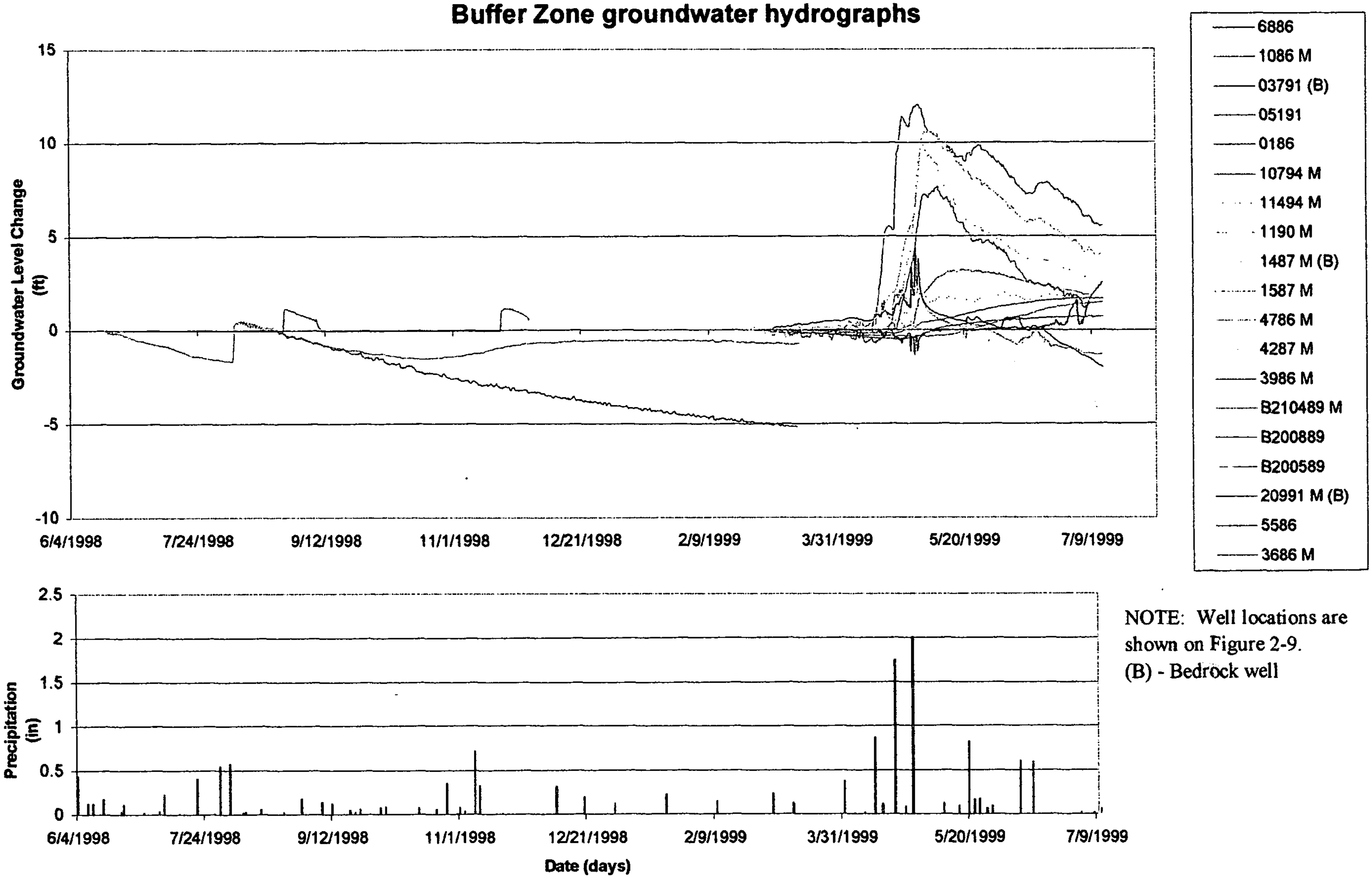
Figure 2-7
Industrial Area groundwater hydrographs



NOTE: Well locations are shown on Figure 2-9.
(B) - Bedrock well

34

Figure 2-8
Buffer Zone groundwater hydrographs



35

Groundwater discharge

Groundwater exits laterally only through the eastern model boundary at Indiana Street. Based on the saturated thickness and the average hydraulic conductivity of the saturated surficial deposits, the lateral groundwater flow rate out of the eastern boundary is similar to the western boundary inflow (~40 ac-ft/yr). Locally, discharge rates are higher through the valley fill sediments than for the colluvium, because of the higher saturated conductivities associated with the former.

Because the surficial deposits are only approximately 10 feet at the eastern end of the model boundary, combined with the relatively shallow topographic gradient, the total groundwater flow across the boundary is not likely to greatly exceed 40 ac-ft/yr under any conditions. Due to the low saturated hydraulic conductivity of the unweathered bedrock material, a negligible amount is believed to flow from the UHSU layer to the underlying LHSU material (RMRS, 1996b).

Groundwater also discharges seasonally at surface seeps, which typically occur along steep slopes (EG&G, 1995a), and are enhanced where slumping of the surficial deposits exposes bedrock, and where the RFA or Number 1 Sandstone subcrops beneath colluvium. Most seeps in the model area are at Antelope Springs in the upper Woman Creek drainage. An estimate of the maximum seepage rate was made during the wet spring of 1995 (RMRS, 1996a). At that time, seepage rates measured at a limited number of locations in the study area totaled ~10 cubic feet per minute. The actual seepage rate at that time was likely significantly higher than this figure, because the 1995 survey did not measure flows at all possible locations, and only surface water flow rates were measured, but not additional ET, or reinfiltration to groundwater. However, these measurements were made during an exceptionally wet period, and seepage at other times is likely to be significantly lower.

Evapotranspiration

The model (Figure 2-2) will differentiate between evapotranspiration (ET) as direct losses from the saturated zone (either through transpiration by phreatophytes, or by direct water surface evaporation), and ET as losses from the unsaturated zone (through transpiration by other plant types). Combined ET losses from the groundwater zone, unsaturated zone, or surface water bodies constitute the single largest hydrologic factor (other than precipitation) to be considered in the SWWB. On an annual basis, the potential ET is greater than the annual precipitation (EG&G, 1995a), but during cooler months of the year the potential ET rate drops below the average precipitation.

Annual estimates of potential evapotranspiration based on data from nearby, offsite stations, range from 46 to 49 in/yr for 1990 (Fedors and Warner, 1993). Wright Water Engineers (1995) indicate that potential evapotranspiration was about 28 inches for 1995. Koffer (1989) estimated potential evapotranspiration to be 50 inches for 1988, while a 24-year average was calculated to be 39 inches. These estimates are based on RFETS weather data, with the exception of maximum sunshine, which Koffer obtained for the Denver area (the source was not reported).

While several estimates of ET have been made for the site, these are *potential* ET, rather than actual ET. Actual ET can be much less than potential ET, depending on moisture availability. However, both potential and actual ET are known to vary spatially and temporally, based on a number of factors that include various meteorological parameters, root density, leaf area index, soil properties, and soil moisture content. Apart from the RFETS meteorologic data and soil distribution, ET at RFETS is uncertain, especially with respect to water usage data for specific plant species, or time-varying in-situ soil moisture conditions at the site. This uncertainty in the spatial and temporal distribution of ET can lead to considerable uncertainty in the overall SWWB. These uncertainties, and other uncertainties inherent in any regional hydrologic model, will be addressed through an uncertainty analysis evaluation, as described in Section 3.5.

Direct loss from groundwater by phreatophyte transpiration occurs principally along surface drainages at RFETS (EG&G, 1995a); direct loss also occurs directly from areas where groundwater is at or very near the ground surface (i.e., seeps, pond perimeter areas), or where surface water is stored (ponds) or collects (depression storage). The remaining portion of the model area loses water to evapotranspiration from the unsaturated zone, primarily through transpiration from the root zone. In these areas, limited water supply to the root zone can limit the losses by evapotranspiration. Some direct losses can occur from bare soil via vapor transport.

2.2.2 Current Industrial Area conceptual hydrologic model

A conceptual model of the current IA is provided because the IA includes hydrologic components that are not included in the BZ (e.g., pipe leakage, storm sewers, building foundation drains, utility trench backfill), and because an integrated hydrologic conceptual model for the IA has not been presented previously. Hydrologic modeling of the IA is important because most of the closure activities at the site will take place within the centralized 400-acre IA. The IA does not include the water supply pond, parts of the 130 building complex, the SID, or the A-, B-, and C-series ponds.

As discussed in Section 1.4, local-scale hydrologic models will be developed for areas (such as the IA) where finer resolution is necessary to achieve the model objectives in conjunction with the site-wide model. Since the site-wide model would provide the boundary conditions for the local-scale model, the boundaries of the local-scale IA model would correspond with surface water drainage boundaries rather than the IA boundary. These surface water drainage boundaries for the IA are shown in Figure 2-9. This modeled area is 635 acres, and includes the entire SID drainage. The western part of the Building 130 complex that drains to the Western Diversion (see Figure 1-1) is excluded from this local-scale IA model area. The Western Diversion structure routes water around the Walnut Creek drainage monitored at location SW093, the northernmost IA drainage.

Modeling the current hydrologic conditions in the IA will provide sufficient understanding of the water sources and flow mechanisms to evaluate the probable hydrologic consequences of

31

various closure scenarios. The current hydrologic conditions within the IA are complex and unique, due to:

- Modification of natural surface conditions by excavation and fill, presence of impervious surfaces, building roof drains, lawns, and other changes in surface cover
- Raw water import and wastewater discharge
- Leaks from pressurized water supply and fire-fighting lines
- Possible preferential groundwater movement through utility conduits and trench backfills
- Infiltration and exfiltration from sanitary sewers and storm sewers
- Groundwater flow to building foundation drains and groundwater remediation systems
- Use of culverts that may alter surface water flow paths, depending upon the magnitude of storm runoff

Figure 2-10 shows the principal hydrologic components that will be considered in the water balance model of the IA. To facilitate the discussion of each of the component processes, a simple annual water balance evaluation of the IA was performed. The goal of this water balance was to provide a more quantitative understanding of the relative magnitude of the annual volumes associated with specific components and processes within the IA, to identify the uncertainty and variability in these fluxes, and to examine apparent inconsistencies in the water balance. This analysis used precipitation measurements for 1999, and existing data from previous studies that gauged surface water flows.

Annual Industrial Area hydrologic component evaluation

Table 2-1 presents the magnitude of the annual flux for the hydrologic components considered to be most important within the IA. The IA in this table corresponds to the surface areas draining to stream gauging stations GS10, SW091, SW093, and SW027. The total area of these subdrainages is 635 acres. These subdrainages comprise the IA water balance area as previously described.. Four primary piping systems were considered in the evaluation: (1) the pressurized water supply system, (2) the sanitary sewer system, (3) the storm sewer system, and (4) the building foundation drain system. The process waste lines were not considered in this evaluation since these systems likely have minimal influence on the current water balance of the IA. Four groundwater remediation systems were also considered in the analysis: (1) the Solar Ponds System, (2) the Mound System, (3) the East Trenches System, and (4) the 881 French Drain System.

Groundwater level data and potentiometric surface maps for April and October of the past several years (i.e., the high and low groundwater table times) suggest that the effect of utility conduits (Figure 2-10) may be minimal, although data from recently-installed piezometers may indicate localized effects. Conceptually, the utility corridors may act as higher conductivity (i.e., sand-backfill) flow paths, although their effect on the groundwater table is likely to be localized and less than the subsurface piping mentioned above. The utility corridor backfill does not

39

Table 2-1

Industrial Area hydrologic component evaluation

Flow component		Description	Area (acres)	Annual flow estimate (ac-ft/yr)	
Precipitation		21.4 inches in 1999	635	1999	1,132.4
Evapotranspiration		No estimate available			
Surface water discharge					
	GS10	Surface water gauge (IA)		1999	126.1
	SW093	Surface water gauge (IA)		1999	184.0
	SW091	Surface water gauge (IA)		1999	0.5
	SW027	Surface water gauge (IA)		1999	29.3
		Total SW discharge			339.9
Wastewater treatment plant discharge				1999	183.6
Water import from DWB				1999	329.0
Groundwater inflow					
IA upgradient flow		Based on Belcher (1995)		Spring 1992	5.5
IA recharge		1 in/yr, excluding 147.5 acres impermeable cover	487.5		40.6
Sanitary sewer exfiltration				1991	7.5
Water pipe leakage		(Estimated at 10% of supply)		1999	32.9
		Total GW inflow			87.6
Groundwater discharge					
IA Downgradient flow		Not estimated			
Sanitary sewer infiltration				1991	13.6
Storm sewer infiltration		See text, Section 2.2.2		1991	80.4
Measured building drain flow				--	26.5
Mound system				1999	1.1
881 Hillside				Avg.	1.2
Solar Ponds system				1999	0.0
East Trenches system				1999	3.6
		Total GW discharge			126.4

40

actively extract groundwater from one location and transport it out of the IA. Instead, it appears that they may redistribute the groundwater locally in the vicinity of the corridor. They may, however, provide pathways to enhance chemical migration.

An estimate of annual evapotranspiration is not included in Table 2-1. Although evapotranspiration could be estimated by subtracting total surface runoff and estimated groundwater recharge from precipitation over the IA water balance area, this approach would be flawed. First, it would assume that the estimated 40.6 acre-ft./yr of groundwater recharge is a valid recharge estimate for 1999. Second, the surface water flow measurements include groundwater flow contributions, so a portion of the groundwater recharge is included again in the surface water discharge that is subtracted from precipitation.

Most of the previous site studies have attempted to determine the average annual recharge. Based on these results, average areal groundwater recharge rates over the non-impervious surfaces within the IA are thought to range from 0.5 to 1 in/yr. The non-impervious surface area within the IA water balance area was determined to be 487.5 acres. Roberts (1997) estimated groundwater recharge rates within the IA that varied from less than 0.01 to more than 3.0 in/yr, but were less than 1 in/yr over most of the IA. As mentioned previously, recharge was also estimated to be 0.5 in/yr within the colluvium/valley fill alluvium of the 881 Hillside area located within the SID drainage (Fedors et al, 1993). A memorandum from W.R. Belcher to T. Lovseth (Belcher, 1995) on IA Flux Estimation provides a much higher recharge value of 2 inches/yr for the non-impervious areas of the IA. However, this estimate included pipe leakage.

Groundwater recharge and evapotranspiration are interrelated, and both vary with the amount and time distribution of precipitation. One study (Roberts, 1996) attempted to simulate the dynamics of groundwater recharge within the RFA using the Hydrologic Evaluation of Landfill Performance (HELP) model. The HELP model attempts to simulate the influences of precipitation, runoff, and evapotranspiration, using an empirical water balance approach. Although the results of the HELP model simulations were inconsistent with the observed groundwater level fluctuations at the site, the study did illustrate the dynamics of groundwater recharge process that will be an important consideration in calibrating transient hydrologic simulation model at RFETS.

Information from previous studies, together with data from 1999, were used to estimate the net gain or loss to the groundwater system from the IA piping systems and the upgradient groundwater inflow to the IA. The upgradient groundwater inflow to the IA of 5.5 ac-ft/yr was taken from the October 1995 Memorandum from W.R. Belcher to T. Lovseth (Belcher, 1995).

Groundwater discharges to footing drains and to groundwater remediation systems were determined from measurements. The estimated footing drain flow of 26.5 ac-ft/yr is thought to be a low estimate, because it was derived from sporadic measurements for only seven footing drains. Furthermore, the measurements for the footing drains for buildings 707, 440, and 444 were estimated from the 1999 low flow from the storm sewer outfalls that receive the flow from these drains. Thus, the annual building drain contribution is probably underestimated. On the other hand, storm sewers may also receive groundwater infiltration, and the measurements

42

may overestimate the building drain contribution. . Flows have not been monitored at the other footing drains because they are inaccessible and/or drain to either a storm sewer or sanitary sewer.

Industrial Area precipitation and groundwater recharge

Precipitation is the largest component of the water balance in the IA. Errors in determining precipitation input will introduce error to model calibration. Fortunately, the precipitation monitoring network at the RFETS site provides good spatial coverage. As part of the initiation of the water balance, a spatial analysis of precipitation will be conducted in order to develop the most reliable estimates of this component to the water balance.

As in the BZ, the recharge and runoff response will vary depending upon whether precipitation is rainfall or snow. Seasonal groundwater level fluctuations within monitoring wells in the IA is similar to that in the BZ, indicating that groundwater recharge occurs mainly during the spring, with minor response to precipitation events at other times of the year. The spatial distribution of groundwater recharge will vary considerably depending upon the distribution of impervious surfaces, the locations of surface water ponding, and the locations for snow removal storage.

Surface runoff and storm sewer infiltration/exfiltration

The main IA surface subdrainages are shown on Figure 2-9. Flows are monitored at the mouth of each of these subdrainages at stations GS10, SW093, SW091, and SW027. Overland flow is particularly important within the IA due to the large proportion of impervious surface.

Overland flow occurs almost immediately after precipitation falls on impervious surfaces and saturated soil. As soon as water begins to pond, it flows laterally in the direction of the surface slope into roof drains, depressions, or small storm drains. When overland flow from an impervious surface flows onto unsaturated soils, a portion may infiltrate, depending upon the infiltration capacity of the soil and the rate of precipitation. Concentrated or channelized flow occurs as the depth of water accumulates in depressions or small storm drains. These flow channels merge and exit the IA at one of the above mentioned gauging stations. Overland flow will also develop on unsaturated soil surfaces within the IA when the rainfall intensity exceeds the infiltration rate capacity of the soil. Furthermore, the infiltration capacity of the soil varies with both the soil characteristics and the antecedent soil moisture conditions. Thus, the surface runoff response at the gauging stations for a particular magnitude precipitation event can vary significantly, depending upon the intensity of precipitation, the antecedent moisture content of the soils, and the condition of the surface. The condition of the surface affects not only the infiltration capacity of the soil, but also the velocity of flow, due to the resistance to flow provided by surface roughness and vegetation.

The 2-foot contour map of the site, the mapping of storm drains and flow directions, and the channel and culvert sections, profiles and elevations in the Drainage Repairs and Improvement

Plan (Hayes et al, 1994) provide sufficient information to develop a distributed model of both overland and channelized flow within the IA. The current ArcView coverages show the total length of the storm sewer system to be 137,890 feet, including 47,940 linear feet of pipe within the IA water balance area. Thus, the storm sewer system consists of approximately 90,000 linear feet of unlined open channels, including the entire SID, as well as ditches along roadways and buildings. More than half of the storm sewer pipe is corrugated metal pipe and culverts, and the rest is made of reinforced concrete, cast iron, polyvinyl chloride (PVC), steel, or asbestos-concrete.

An estimate of storm sewer infiltration of approximately 80.4 ac-ft/yr was provided in the Zero-Offsite Water-Discharge Study (ASI, 1991b). This estimate was derived using flow measurements during non-storm periods at gauging stations SW023 and SW093, the major storm sewer discharge points to Walnut Creek. Storm sewer infiltration estimates at the measured locations are thought to include a flow contribution from at least two building drains, i.e., Building 707 and Building 771. Low flow measurements during 1999 at GS40 indicate possible building drain flows of about 9 ac-ft/yr from Building 707. There are apparently no measurements for drain flows from Building 771. From a review of building foundation drain plans and recent field inspections, it appears that a portion of the building 771 footing drain outfalls to a surface storm drain and would be included in the flow measurement at proposed gauging station GS44 before entering the buried storm sewer pipe that outfalls at SW093. However, a portion of the footing drain also appears to flow directly into the buried storm sewer that outfalls at SW093. Temporal response of the surface water gauging stations GS10 and SW093 (see Figure 2-5) indicates that even during significant dry periods there is a groundwater component of flow from building drains and perhaps from storm sewer infiltration.

Pipe leakage

Water imported for domestic (potable) and raw water (process/cooling) use affects the water balance of the IA through pressurized pipe leakage and through exfiltration from the sanitary sewer system. The discharge of WWTP flows, which consist largely of imported water, affects the water balance of Walnut Creek within the BZ. As indicated in Table 2-1, leakage from domestic and raw water pressurized pipes may be a significant contribution to groundwater within the IA. The estimate of about 10% loss from pressurized water pipes (39.9 ac-ft/yr) has been based on engineering judgment and has not been verified by site data. Another possible external source of water in the IA water balance is sanitary sewer exfiltration. The Sanitary Sewer Infiltration/Inflow and Exfiltration Study of the Zero-Offsite Water-Discharge Study (ASI, 1991a), estimated 7.5 ac-ft/yr of sanitary sewer exfiltration.

The contribution of imported water to the IA water balance could potentially be determined by a detailed building-by-building accounting of consumptive and evaporative losses of domestic water and raw water supplies, and measurement of return flows to the sanitary sewer system. Presumably, these studies would provide better estimates of pressurized pipe leakage, and groundwater contributions due to exfiltration from the sanitary sewer system. However, these studies have not been performed, because of the difficulties in instrumenting or even locating individual pipes entering and leaving every building. Furthermore, leakage from pressurized pipes, and infiltration and exfiltration from sanitary and storm sewers, are typically estimated as residual terms in the water balance and are therefore subject to error in the measurements or estimates for other components of the water supply system water balance.

The Zero-Offsite Water-Discharge Study (ASI, 1991a) used measured water supply (raw water and domestic water), discharge measurements of flows at 6 locations within the sanitary sewer system, and theoretical wastewater production estimates to evaluate infiltration and exfiltration from the sanitary sewer systems. The reliability of the infiltration/exfiltration estimates was uncertain because there was no reliable method for measuring or estimating pressurized line leakage, and the theoretical wastewater production estimates were uncertain. These estimates were derived from a combination of measured and estimated accounts of consumptive and evaporative losses of domestic and cooling water uses, and estimated sewer return flows from domestic water use and cooling tower and air washer blowdown. The cooling tower and air washer blowdown contribution increases during dry weather, thus masking sanitary sewer infiltration/inflow contribution determined from this approach.

The WWE study (1995) questions the magnitude of infiltration/exfiltration from the sanitary system, because there is little change in WWTP flows between seasons, and most of the sanitary sewer system was rehabilitated during the mid-1980s. Review of potentiometric surfaces supports the conclusions of the WWE study with respect to pipe leakage. While some building drains appear to influence groundwater levels, water supply pipes and sanitary sewer pipes do not appear to have as much influence. Measured building drain flows are much lower than the estimates of pipe leakage, suggesting that pipe leakage may have been overestimated.

Although depth to groundwater within the IA tends to be greater than the 6-foot depth of pressurized pipes, there is still a strong seasonal fluctuation in groundwater levels that might not occur if pressurized pipe leakage and sanitary sewer infiltration/exfiltration were significant components of the groundwater balance as suggested in Table 2-1. Furthermore, seasonal fluctuations in groundwater levels may result in seasonal fluctuations in pipe infiltration/exfiltration depending upon the lateral and vertical spatial distribution of pipes.

Sanitary sewer elevations have been determined at all manhole locations, and pressurized water pipes are generally installed at a depth of 6 ft BGS at the site. Pipe leakage will occur at discrete but unknown locations within the pipe network. This aspect can be viewed as a heterogeneity that may be averaged over a sufficiently large representative elementary volume. Due to these heterogeneities, it is unlikely that water balance predictions would be significantly improved by calibration to measured water levels at a specific well near a pipe, as compared to calibration to the overall potentiometric surface within a larger sub-area of the IA.

45

Conclusion

Given the assumptions inherent in deriving the estimated values for each of the hydrologic components within the IA, considerable uncertainty surrounds the estimates. While Table 2-1 is not a water balance, the comparisons in Table 2-1 are useful for an initial assessment of the relative significance of these components to the overall IA water balance. Given the uncertainty in the hydrologic components of the IA, and that direct measurement of many of these components is not possible or practicable, calibration of a transient groundwater model will be used to improve the reliability of quantification of each of the hydrologic components.

46

3.0 Scope of Work

This section formally presents the Scope of Work for this project. Some data review and conceptual model development have already been performed to facilitate preparation of this document. However, for completeness, this section describes all Tasks, including those already partially completed. The Task numbers used correspond to those used in the Statement of Work, for consistency with the Statement of Work, and for accounting purposes.

RFETS closure activities and final end-state configuration have the potential to significantly alter groundwater and surface water flow. Further, many RFETS closure decisions are dependent on water balance information. In short, the SWWB must evaluate current water conditions and how they may change through site closure. The following tasks outline the specific work required to complete the SWWB.

3.1 Task 1 - Work Plan development

This Work Plan has been prepared in accordance with the *Statement of Work for Site-Wide Water Balance Subcontractor Support at the Rocky Flats Environmental Technology Site* (November 2, 1999), the *Site-Wide Water Balance (SWWB) Project Planning DQOs* (August 1, 2000), and the *Actinide Migration Evaluation DQOs* (April 11, 2000). This Work Plan outlines the conceptual hydrologic model, the model code(s) selection criteria, the potential data needs, the water balance scope, and the schedule. The conceptual hydrologic model of the site provides the basic framework for development of the numerical model. It includes the vertical, horizontal, and temporal boundary conditions of the system, the relevant components and processes and their interrelationships, and the spatial and temporal resolution needed to support site closure decisions. The conceptual hydrologic model is developed based on the review and analysis of existing data (Task 2). Furthermore, the conceptual model will be revised and updated throughout the SWWB project.

3.2 Task 2 - Review existing data

Existing reports and data were reviewed and analyzed to develop the conceptual hydrologic model and to identify additional data needs. Reports already reviewed as part of this effort are listed and described in Appendix B. All data, conceptualizations, modeling results, and conclusions have been reviewed in terms of how this information will provide the needed minimum input to an integrated hydrologic model of the site. Although final model code selection has not been completed, the review of available data and conceptualizations has been performed in the context of application of a fully integrated, physically based, continuous, distributed-parameter, numerical modeling code. This represents the most data intensive type of model that could be applied to the site and ensures that all of the relevant factors in any modeling effort will be considered in the data review. It also provides a good way to identify data limitations early on, and how these data limitations might impact modeling objectives.

47

As a general note, modeling data can be broken down into three different types. The first type is the model input, parameter, or boundary condition that would be critical to development of the numerical model. Examples of these include channel cross-sections, channel slope profiles, surface flow friction factors, pond dimensions, conductivity values, stratigraphy, and surface water and groundwater flows or heads at a boundary. Particular emphasis will be placed on obtaining data that are determined, either through direct experience or through preliminary water balance evaluations, to have the most significant effect on the outputs (i.e., stream flow or groundwater flow) of integrated hydrologic models. Less accurate data, or poor spatial/temporal data distributions, will result in less certain model output.

The second type is data that is used as a calibration target. Although perhaps not quite as important during model development, these data are critical to the calibration phase of the model. Examples include pond inflow/outflow as a function of time, gaining/losing reaches, groundwater levels, foundation drain flows, and estimated evaporation rates at ponds. These types of data describe the system response to various boundary conditions or input.

The third data type is the interpretative information related to model output that may not be known with sufficient accuracy to serve as a calibration target, but can be helpful in evaluating consistency of model predictions with other studies. Examples include estimated recharge rates, estimated infiltration rates, and previous water balance evaluations. This type of data or information is not required for model development or calibration. These data would generally not be identified as a data need but, if already available, will be useful for comparison with the SWWB model and will be used for model evaluation.

The status and source of these three types of data and information have been assembled in a comprehensive data evaluation matrix. After review of existing data, previous investigations, and existing and formerly exercised models, the additional data needed for the water balance modeling have been identified. The specific additional data to be collected for the water balance modeling year 2000 are summarized in Table 3-1.

3.3 Task 3 - Initiation of the Water Balance

The selection of the model code(s)[3] and the development of the site-specific modeling input parameters needed to perform the water balance will be completed based on the review of existing data, the SWWB Project Planning DQOs, the AME DQOs, and the review of this Work Plan. The relevant subtasks involved in initiation of the Water Balance are discussed below:

[3] In this work plan, the term *model* refers to a mathematical model that represents the field situation, while the term *model code* refers to the program or set of commands that is used to solve the model. A *model* is site- and objective-specific, whereas a *code* is generic and can be applied to many sites and problems.

48

Table 3-1
Additional 2000 data collection

Item	Description		
Raw water/ treated inflow	• Collection and translation of data from site water treatment plant (B124) for 2000. • Collection of Denver Water Board (DWB) record for 2000.		
In-situ treatment systems	• Download electronic record; maintain systems; work up data for remainder of 2000 for: Mound Plume, Solar Ponds Plume, and East Trenches Plume.		
Footing drains	• Maintain flow measurement devices and work up data at GS22, B371 Basement, and B371 Sub-basement. (Several other footing drain locations are monitored as part of RFCA and require no "additional" data collection.) • Check flow rate at Building 881 in July, September, and December.		
Culverts	• Compile a list of culverts in the buffer zone, including size, approximate slope, and % full of sediment. • Compile a new list of culverts in the Central Avenue ditch including size, approximate slope, and % full of sediment.		
New boundary monitoring locations	• Install, operate, and maintain equipment at GS45, GS46, GS47, GS48, and SW009. Obtain data from Broomfield equipment at Boulder Diversion and McKay Extension splitter.		
Continuous groundwater level monitoring (12 additional wells)	46192 5386 B402689 0790 00293	P416189 3386 B302889 B405489 5286	11994 (off site – east of Indiana Street on Walnut Creek)
Quarterly groundwater level monitoring (73 wells)	5187	43593	60299
	62393	71494	60399
	B405989	11394	60499
	13291 (903 Pad SCA)	12094	60599
	46392	68194 or 68294	60699
	B405889	64595 (seep WP)	60799
	B304789	64695 (seep WP)	60899
	06591 (903 Pad SCA)	64795 (seep WP)	61099
	20791	65195 (seep WP)	61199
	P207389	65395 (seep WP)	61299
	P314089	65495 (seep WP)	61399
	P219089	65895 (seep WP)	61499
	B208689	66195 (seep WP)	22098
	P209689	66695 (seep WP)	21898
	B203189	66795 (seep WP)	21698
	B206689	66895 (seep WP)	21498
	B304889	67095 (seep WP)	21298
	10991	67195 (seep WP)	21098
	12391	67295 (seep WP)	20898
	02591	67395 (seep WP)	20698
	75092	67495 (seep WP)	20498
	39691	67595 (seep WP)	20298
	35991	60099	20098
	42993	60199	22298

49

3.3.1 Model code selection

This section describes the approach that will be taken in selecting an appropriate numerical code (or codes) to be used in the SWWB project. Selection of an appropriate numerical code for the SWWB is influenced by several factors. The selection process will consider the following general factors at a minimum:

- The selected code must be available in the public domain (non-proprietary).
- It must be capable of handling the various types, quantity, and quality of available data, and the complexities of the conceptualized hydrologic system.
- It must be demonstrated that the code selected for the SWWB has distinct advantages over other existing codes.
- Specific standards, if they exist, should be considered in the selection process.

Model code selection will be based primarily on the SWWB project objectives specified in Section 1.1. A separate *Model Code and Scenario Selection Report* will be issued following approval of this Work Plan.

A physically based, distributed, continuous simulation model code will be needed to accomplish the project objectives. Event-based model codes cannot be used for water balance evaluations or for predicting the interrelationships between surface water and groundwater, because they do not include the hydrologic processes operating between precipitation events. Nevertheless, event-based model codes may still be used as a supporting tool to address specific questions associated with the water management plan.

Physically-based, distributed model codes take into account spatial variability of processes, inputs, boundary conditions, and system characteristics. These considerations are needed to enable prediction of the expected changes in the hydrologic system resulting from the spatial changes in site characteristics that may occur during site decommissioning and closure. On the other hand, some degree of lumping is required in all models, based on grid resolution and on the space and time resolution of input information, and no model code provides a complete representation of complex hydrologic processes.

Major challenges to using a physically–based, distributed hydrologic model code include scale issues and the choice of the grid. Grid issues particularly arise at the interfaces of sub-domains and at the groundwater-surface water boundary. The capability of adjusting the scale of the model is another capability provided by physically-based, distributed hydrologic model codes over other modeling approaches (i.e., lumped, or conceptual).

3.3.2 Model input parameters

Assuming that a physically-based, distributed parameter code is selected for the SWWB, Table 3-2 summarizes the types of model input parameters to be specified. If another type of model (i.e., more conceptual, or lumped), or a coupling of independent models is selected for

50

the SWWB, these input parameters will change: it is expected that the number will decrease, because physically based models are the most data-intensive types of model available.

A summary progress report, results of initiation of the water balance, and the proposed work for fiscal year 2001 will be prepared by September 25, 2000.

3.4 Task 4 – Model calibration

Calibration of the model will be performed following initiation of the water balance. If multiple model codes are used to simulate the conceptual hydrologic model, calibration will include integration of the simulation codes. The model calibration will also include error and particle tracking analyses. Monthly updates (summaries) of the calibration progress will be prepared during the calibration work. These monthly summaries will be short and concise.

The model calibration year is nominally 2000, which also represents current conditions against which future scenarios will be compared. However, model calibration will start before all the additional data for 2000 have been obtained. Therefore, the calibration year will include data from most of the additional 2000 monitoring program, and some of the preceding year's monitoring program. This is the best currently-available data set, both in terms of data frequency and areal coverage, to constrain boundary conditions and the internal system response. It appears that 2000 will be a drier-than-average year. However, even though the overall annual precipitation may be below average, this will not limit the validity of the model calibration. This is because the hydrologic system is event-driven, and notable precipitation events have been recorded, and the hydrologic system response has been monitored, during 2000. Also, surface water management data (pond levels, transfers, and discharges) for 2000 are available. To further support the model calibration, additional model validation runs will be performed for historic periods, as described in the *"Model Validation"* section, below.

Model calibration targets include measured groundwater levels and surface water flows. Surface water flows are recorded every 15 minutes. It is anticipated that, for computational efficiency, the modeling time increment will need to be performed for time increments longer than 15 minutes. Therefore, surface water flow data may be averaged to correspond with the time increment of modeling.

During calibration, analysis and modeling will be performed as required to further refine the site conceptual model and to facilitate coupling of hydrologic components into an integrated hydrologic model. This effort will include spatial and temporal analysis of precipitation, analysis and modeling of vadose zone processes and groundwater recharge, and analysis and modeling of the IA groundwater balance. The initial analysis and modeling may also include development of a simplified, coarse grid, fully integrated model of the site. The purpose of the initial coarse grid model is to provide an assessment of the appropriate grid resolution, and to establish the sensitivity of the integrated hydrologic system to various model input parameters and various refinements of the geologic model.

42

Calibration of an integrated hydrologic model requires a considerable number of input parameters. Some current literature (Beven, 1996) indicates that these models can be over-parameterized, meaning that there are so many parameters that it is impossible to reach a reasonable solution. However, with a well-constrained system, and with adequate data quantity and quality, this becomes more feasible. Furthermore, once the effort has been made to develop reasonable model input distributions in time and space, integrated, physically based models can be constrained by many different types of calibration data types. For example, in addition to "standard" calibration against groundwater levels and surface flows, additional constraints of the system can be imposed on the model that might include the following:

- Gaining/losing reaches
- Backwater areas
- Seepage areas
- Ponding areas
- Peak flow response in channels per event
- Plume migration patterns relative to particle tracking evaluations

Table 3-3 summarizes calibration targets and their relative level of constraint.

Assuming that the model code selected is an integrated, physically-based, distributed hydrologic model, no automatic calibration techniques will be used (i.e., PEST, or a maximum likelihood method). These methods are only useful to model codes that are much simpler and with much fewer input parameters. Therefore, manual calibration will be used as the only means of calibrating the model. During the initial analysis, or if loosely coupled model codes are selected for modeling hydrologic components, then a parameter estimation code, such as PEST, may be used in combination with manual techniques for model calibration.

The general approach to manual calibration of a physically based model will be as follows:

1. Input initial estimates for distributions and specific model input values.
2. Simulate the calibration period using these inputs.
3. Plot observed versus simulated values.
4. Calculate the mean and weighted residuals, at primary calibration targets.
5. Change input parameters in a fashion that minimizes the residuals, weighted mean etc.
6. Evaluate simulated results against other calibration targets (i.e., seepage areas, ponding areas etc.).
7. Change input parameters to better match these constraints.
8. Continue steps 1 through 7.

3.4.1 Sensitivity analysis

Following calibration, a sensitivity analysis will be performed to identify the most sensitive parameters. Model calibration is a rigorous means of obtaining a general sensitivity of each

Table 3-3
Model calibration targets

Output variables - calibration targets	RFETS source	Type	Comments
Potential head of saturated zone Groundwater hydrographs	RMRS database	Primary	Selected wells will be chosen that do not reflect recovery effects caused by sampling, or other significant localized factor not considered in the model.
Stream discharge (each gauge) time series Peak flow rates	RMRS database	Primary	Match at locations near eastern boundary along Woman/Walnut Creeks will be better constrained. Time to peak should match reasonably well.
Streamflow hydrographs - specific events	RMRS database	Primary	General response shape of hydrograph should match well, including tails.
Steam stage (each gauge) time series	RMRS database	Secondary	Greater degree of uncertainty associated with stage (local structure will be lumped in model)
IA surface water flow gauge data Hydrographs	RMRS database	Secondary Secondary	Calibration against flow rates (not stage) General hydrograph should be matched, though uncertainties in sources of flow will limit exact match here.
Peak flow rates	RMRS database	Secondary	Model should roughly estimate this, though the time to peak may vary because of uncertainties of inflows.
Potential head of saturated zone Spatial distribution (gradients, flow directions)	RMRS database	Secondary	Flow directions/gradients should match known.
IA footing drain flows	RMRS database/ SW group	Constraint	Greater degree of uncertainty
WWTP flows	RMRS database	Constraint	Combined flows uncertain
Landfill surface/subsurface inflows			
Ephemeral Reaches (locations, wet/dry duration, stage/Q)			
Water contents of the unsaturated zone	ASI (1991a); Fedors and Warner (1993)	Constraint	Only specific locations and for a given time.
Flood zone maps	Existing studies		Only valid for simulations of flood events
Chemical distributions	RMRS database	Constraint	Model should roughly support plume migration directions/velocities, though many factors must be considered.
Gaining and losing reaches	Fedors and Warner (1993)	Constraint	Only really available for Woman Creek
Groundwater seepage rates and locations	RMRS (1996)	Constraint	Available for seeps inventoried. Additional seeps are known to exist but limit this comparison
Total estimated water balance - other methods	ASI (1990) ASI (1991c) EG&G (1992) WWE (1995)	Constraint	Can be used to compare results of SWWB to other modeling efforts, at least for specific hydrologic processes where appropriate.
Baseflow estimates		Constraint	

* Based on conceptual model presented in Section 2.0 of Work Plan

model parameter, and as such provides a means of ranking these parameters. As part of this analysis, parameters will be adjusted individually, or in combination, to identify the most sensitive parameters for model output. Those model input parameters that influence simulated results the most will be used as the basis for conducting an uncertainty analysis.

3.4.2 Model validation

The calibrated model will be checked against historic (1995-1999) data to evaluate and validate its overall performance. In addition, model validation may be performed against the complete 2000 data set as it becomes available later in the calibration process. This longer data set will likely include a wider range of climatic conditions than the calibration period. It is also understood that surface water management operations were different in the validation period to the calibration period, and this data will be incorporated into any validation modeling runs that are performed. However, it should be recognized that the more complete data set collected for 2000 (Section 1.3), which helps constrain boundary conditions and the internal system response, will not be available for this extended model validation simulation. Also, earlier data may contain greater uncertainties than the calibration year. Therefore, results of this simulation will not be scrutinized to the same level as that of the calibration year. For example, 1995 was an extremely wet year. Continuous groundwater level data, and a good coverage of groundwater quarterly levels are available for that year. However, the surface water data, while very good, is not accurate for maximum flows, due to overtopping of flumes, etc. As a result, the model validation for these periods of 1995 is not well constrained. Nevertheless, if validation runs indicate a significantly different hydrologic response to events compared with the calibrated model, the calibration may be revised.

3.5 Task 5 - Modeling scenarios

3.5.1 Scenarios

Note that future scenarios will be described in detail in the *Model Code and Scenario Selection Report*. These scenarios will be modeled after completing model calibration. The modeling subcontractor will simulate a focused set of "what-if" scenarios. The specific scenarios to be performed will be defined by K-H. They will be intended to:

- Evaluate the effects of surface and subsurface features (such as covers, building foundations, utilities, and passive treatment systems) on the water balance under current conditions and at site closure
- Develop management strategies for pond configurations and wetlands conversions
- Evaluate impacts of potential IA final configuration(s) on the BZ water fluxes

Local-scale hydrologic models will be developed as required for the specific area and objective of each scenario.

55

3.5.2 Uncertainty analysis

Completion of the scenarios will include an uncertainty analysis evaluation. This is an important process that attempts to define the reliability of predicted output variables that are simulated using the calibrated model. Examples of output variables that will be considered in the uncertainty analysis will include, but are not limited to the following:

- Groundwater elevations at calibration target locations
- Surface water volumetric flow rates at calibration target locations

To the extent possible, a Monte Carlo analysis (Melching, 1995) will be performed as a means of assessing the reliability of model output for a given range of input parameter uncertainty. The Monte Carlo approach typically requires many simulations where input parameters (singly, and in combination) are randomly varied according to a specified probability distribution to generate reasonable estimates of reliability of predictions. Only the most sensitive parameters determined through the sensitivity analysis will be incorporated into the Monte-Carlo Method. The Latin-Hypercube Sampling method may be used to perform the Monte Carlo simulations, as it offers a more computationally efficient approach compared to standard Monte Carlo Methods.

The feasibility and success of performing the uncertainty analysis using Monte Carlo methods will be dependent upon the complexity of the model and the difficulties in model convergence. A physically based model code will result in a very complex and highly non-linear model of the system. This can limit the success of applying Monte Carlo methods for uncertainty analysis. For example, assuming that a sophisticated and physically based code is selected for the SWWB, this may result in a calibrated model that converges to a solution for only a given subset of what may be considered a reasonable range of input parameter values. In other words, the system may be so non-linear or complex that the numerical code only converges using a given range for a specific model input parameter. In other cases, the combination of specific input parameters may also result in the model not being able to converge to a solution. In these cases Monte Carlo methods cannot be used.

3.6 Task 6 - Modeling Report

A Modeling Report will be prepared upon completion of the work. This report will include, but not be limited to, the following:

- Objectives and purpose of the modeling effort
- Description of the model
- Results of model calibration and error analysis
- Results of the modeling scenarios

54

3.7 Quality assurance

The quality assurance (QA) program for the SWWB is based on the project objectives described in the Site-Wide Water Balance (SWWB) Project Planning DQOs, and on the detailed protocols, procedures, methodology, and documentation standards presented in the AME DQOs. Both sets of DQOs are included in Appendix A.

The SWWB Project Planning DQOs define the problem, identify the decisions that will be made, define the study boundaries, identify the model inputs (existing and potential additional data), spatial and temporal model outputs, scenarios for current and closure conditions, develops the decision criteria, specifies the acceptable limits on the decision errors, and other issues to which the model may be partly applicable. Results of the SWWB may be applicable in part to the AME investigations. Therefore, where relevant, the SWWB QA program will follow the AME DQOs.

The AME DQOs apply to a wider range of issues than the SWWB, including research into the mobility and potential migration of plutonium, americium, and uranium via pathways in the site environment. These pathways include runoff and diffuse overland flow, surface water flow, groundwater transport (both saturated and unsaturated), erosional transport, and airborne transport. Because the SWWB does not deal with actinide fate and transport in any media, or with erosional or air flow, these aspects of the AME DQOs do not apply to the SWWB. In particular, the SWWB does not contain any analytical work; therefore, there are no QA requirements for analytical data precision, accuracy, representativeness, comparability, completeness (PARCC), or validation of analytical data. However, the overall quality of the data will impact the model error limits and affect the overall decision error. Table 3-4 summarizes the processes, model needs, data availability, and data uncertainty that are specifically applicable to the SWWB.

Model Requirements

As stated in the AME DQOs, models must comply with DOE QA requirements which are described in DOE Order 414.1, *Quality Assurance*. Specifically, Section 4.b.(2)(b)(1), (2), and (4) state that "[work] must be designed using sound engineering/scientific principles and appropriate standards" (i.e., defensibility), "... must incorporate applicable requirements and design bases", and "the adequacy of [work] must be verified or validated by individuals or groups other than those who performed the work". Section 4.b.(2)(d)(1) requires "Inspection and testing of specified items, services, and processes must be conducted using established acceptance and performance criteria".

The requirements of defensibility, design basis, and acceptance/performance criteria will be communicated internally and externally at appropriate stages during the project, including the Model Code Selection Report, regular Calibration Reports, and the Final Project Report.

51

Table 3-4

SWWB processes, model needs, data attainability, and data uncertainty

Process	Model needs	Data availability	Data uncertainty
Surface water flow. Includes diffuse overland and channel flow	Climate/precipitation Design storm data for future scenarios and sensitivity analysis.	Meteorology station data from meteorologic group. Up to 95% climate data available (temporally) for 1995-to date.	Precipitation, 0.01 inch resolution on 5-minute increments (SW group) and 15-minute on met tower; temperature, 1°C per 15 minutes; wind, 1 mph per 15 minutes.
	Vegetation: distribution, type, root depth and density, growth and water use	ArcView vegetation type and distribution maps available through RMRS GIS	Vegetation distribution and identification has been well characterized. The main source of uncertainty is the absence of systematic soil moisture profiling; hence seasonal growth, root density, and water usage will be assessed through modeling based on PET and soil water availability.
	Landscape slope values, hill slope dimensions	2' and 5' GIS contour mapping	Contour survey accuracy (+/- 2' vertically, +/- 20' laterally)
	Channel geometry (including slope and cross-sectional areas, culvert locations, obstructions, losing/gaining reaches)	Contained in Site Master Plan and 1999 field survey for HEC-6T model	Contour survey accuracy (+/- 2' vertically, +/- 20' laterally)
	Impermeable areas (pavement, buildings, etc.)	Hydrogeological Characterization Report (EG&G, 1995a), RMRS GIS, Facility Engineering drawings etc.	Mapping accuracy (+/- 10' laterally)

58

Table 3-4 (continued)

SWWB processes, model needs, data attainability, and data uncertainty

Process	Model needs	Data availability	Data uncertainty
Surface water flow (continued)	Controlled aspects of the hydrologic system, (pond releases, pond water height, WWTP operations, piped or ditch discharges)	RMRS surface water group and WWTP Operations	Measurement and documentation accuracy (pond levels ±0.05'; depth conversion to volume, ±10-15%; pond volume, ±0.1%; pond discharges, ±10-15%; WWTP incidental water, ±50%; internal waste streams, ±25%; short-term pipe discharges ±40-50%).
	Stream flow and stage hydrographs at all inflow and outflow points.	7-year record available, length of record varies by sampling station	10-15% of total flow (annual basis), up to 20% at area velocity meters
Unsaturated Zone Flow	Unsaturated zone hydraulic parameters and appropriate boundary conditions. Soil characteristics (soil type, texture, porosity, water content, residual moisture, hydraulic conductivity, bulk density, organic content, depth, cover, roughness, air-entry pressure, retention curve parameters, etc).	Most data available from CSU and OU studies. Soil moisture conditions are not available, though continuous groundwater table monitoring provides response.	Unsaturated zone hydraulic parameters are reasonably well known across the site for major hydrostratigraphic units. Depth to groundwater and bedrock generally are known to ±10%.

59

Table 3-4 (continued)

SWWB processes, model needs, data attainability, and data uncertainty

Process	Model needs	Data availability	Data uncertainty
Subsurface pipe leakage	Volume of imported water	RMRS surface water group.	Volume of imported water is not accurately metered, and will be estimated. The anticipated error may be up to ±50% of recorded instantaneous and cumulative flow rates.
	Piping location, invert elevations, depths, type, estimated leakage from pressurized pipelines, and infiltration/exfiltration for sewer lines, footing drains, utility corridors, storm sewers, and process lines.	Facilities Engineering utilities plans and drawings. Updates for storm/sanitary lines. SW group - direct information on footing drains. RMRS GIS system.	Available plans may not show all piping details. Leakage from pressurized pipelines is unknown, and will be estimated. Infiltration/exfiltration studies for sewer lines have been performed. The anticipated error may be up to ±35% of recorded instantaneous and cumulative flow rates.
Groundwater flow	Hydro-stratigraphic unit definition, hydraulic properties and water level data. Boundary conditions, including groundwater inflows and outflows.	Geologic and Hydrogeologic Characterization Reports (EG&G, 1995b, 1995a). Existing RMRS GIS and database files will also be used to supplement information within the two reports.	Varies: greatest variability is in definition of depth of weathered/unweathered bedrock contact, and determination of hydraulic properties. It is estimated that this may be uncertain within ±20%.

60

Table 3-4 (continued)

SWWB processes, model needs, data attainability, and data uncertainty

Process	Model needs	Data availability	Data uncertainty
Groundwater flow (continued)	Disturbed land areas (road fill, landfills, building excavations, etc.)	As above, plus USGS surficial mapping. Facilities Engineering records for depth of building excavations.	Mapping accuracy (+/- 2' vertically, +/- 20' laterally) and depth to geologic contacts (±10%).
	Remediation systems	RMRS GIS, groundwater group, surface water group, operations group.	Installation documentation and mapping accuracy (+/- 2' vertically, +/- 20' laterally). Operational data accuracy (+/- 0.01' vertically).

61

As described in Sections 3.4 and 3.5, model sensitivity will be determined through the calibration process, and the most sensitive parameters will be further evaluated through an uncertainty analysis for each simulated scenario. The processes of calibration, sensitivity analysis, and uncertainty analysis will follow the procedures described in the AME DQOs. The data and analyses generated from these processes will allow "third-party" model verification and validation, as described in the AME DQOs.

SWWB-specific quality assurance will include the following:

- Detailed documentation and rationale for all assumptions and parameters selected
- Detailed documentation of model inputs and outputs
- Detailed documentation of benchmarking tests for groundwater, unsaturated zone, and surface water scenarios, to confirm calculation accuracy

Documentation will be performed using forms and spreadsheets. Examples of documentation spreadsheets are shown on Figures 3-1 and 3-2. Figure 3-1 shows a model calibration tracking spreadsheet used to document the calibration process and interim model parameters. Figure 3-2 shows a model calibration summary spreadsheet used to summarize final calibrated model parameters. Tracking and documentation forms will be tailored to site-specific requirements as the project progresses, and will be presented in regular Calibration Reports and the Final Project Report.

3.8 Schedule and deliverables

Table 3-5 shows the projected milestones, deliverables, and schedule for completion of Tasks 1 through 6. Note that Task 2 – Data Review And Analysis – will continue through the life of the project, and therefore has no specific milestone or deliverable.

CP2

Table 3-5
Schedule, milestones, and deliverables

Task	Description	Milestone/Deliverable	Date
1	Work Plan	Final Work Plan	August 15, 2000
2	Data review	No specific milestone	Ongoing
3	Initiation of the Water Balance	Initiation of the water balance, Summary Progress Report, presentation, & Proposed Work for fiscal year 2001	September 25, 2000
4.	Model calibration	Monthly Calibration Progress Summaries	Monthly, 15th day of following month, final presentation by May 1, 2001
5.	Model scenarios	Presentation of Scenario Results to SWWB working group	August 1, 2001
6a	Model Report	Draft Modeling Report	August 15, 2001
6b	Model Report	Presentation of Results	August-Sept. 2001
6c.	Model Report	Final Modeling Report	September 24, 2001

43

Figure -1
Model Calibration Tracking Form

Simulation ______________________________

Assumptions: ______________________________

____

____

____

Boundary Conditions ______________________________

Run Time Settings ______________________________

Layer Type(s) ______________________________

____

Model Input												Model Output									
File Name	Timestep	Conductivity (ft/d)					Recharge			Solver	Comments on Input	Mass Balance % Discrepancy	Zone Budget						Calibration		Comments on Output
		Property #	Geology	Kx	Ky	Kz	Property #	Surface Feature	(in/yr)					Total	1	2	3	n	Obs. Head	Calc. Head	
													Constant Head In (ft^3/d)								
													Constant Head Out (ft^3/d)								
													Recharge In (ft^3/d)								
													Constant Head In (ft^3/d)								
													Constant Head Out (ft^3/d)								
													Recharge In (ft^3/d)								
													Constant Head In (ft^3/d)								
													Constant Head Out (ft^3/d)								
													Recharge In (ft^3/d)								
													Constant Head In (ft^3/d)								
													Constant Head Out (ft^3/d)								
													Recharge In (ft^3/d)								
													Constant Head In (ft^3/d)								
													Constant Head Out (ft^3/d)								
													Recharge In (ft^3/d)								

Figure 3-2

Model Calibration Summary

Summary	
Project	
Area	
Modeler(s)	
Type of model	
Code	
Time modeled	
Dimensions	
X coordinates	
Y coordinates	
Coordinates	
Rows, Columns	
Grid spacing	
Boundaries	
Surfaces	

Unit	K_x (ft/d)	K_y (ft/d)	K_z ft/d)	S_s (1/ft)	Sy	Porosity

Wells	
Recharge/Discharge	
Solver	
Layer type	

65

00-RF-02373

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46

SW-A-004099

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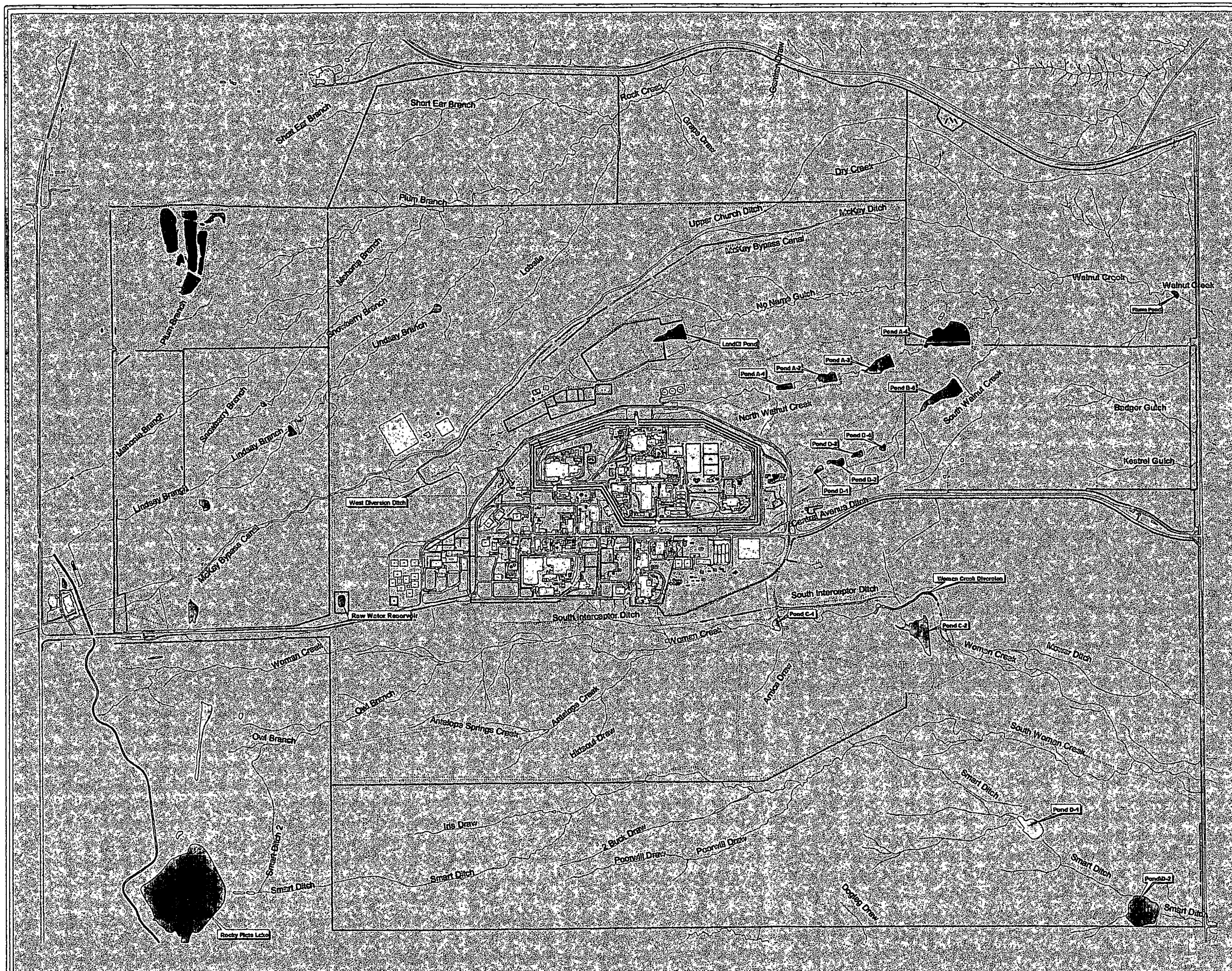
68/68



Rocky Flats Environmental Technology Site
(Site Wide Water Balance Project)
August 2000

Figure 1-1
Location Map

12

Surface Ponds
Approximate SWWB Model Boundary
Streams gssedits.shp
Dirt Roads (9/99)
Paved Roads (9/99)
Fences (9/99)
Buildings/Structures

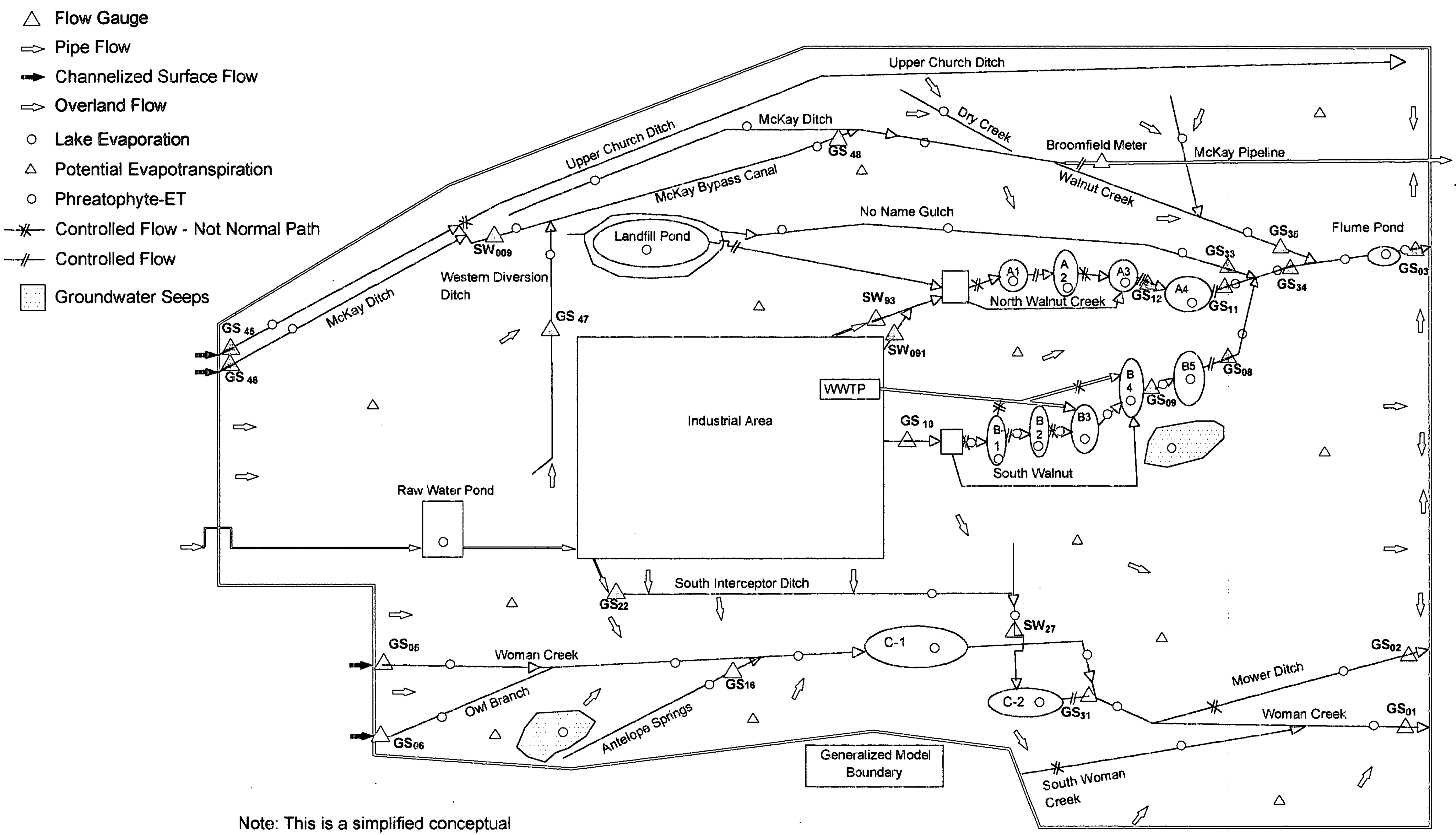
N

1000 0 1000 2000 Feet

Rocky Flats Environmental Technology Site
(Site Wide Water Balance Project)
August 2000

Figure 2-1
Approximate SWWB
Model Boundary

22



Note: This is a simplified conceptual representation of surface water flow components and is not intended to be comprehensive, to scale, or spatially accurate.

Figure 2-2
Conceptual Model Components

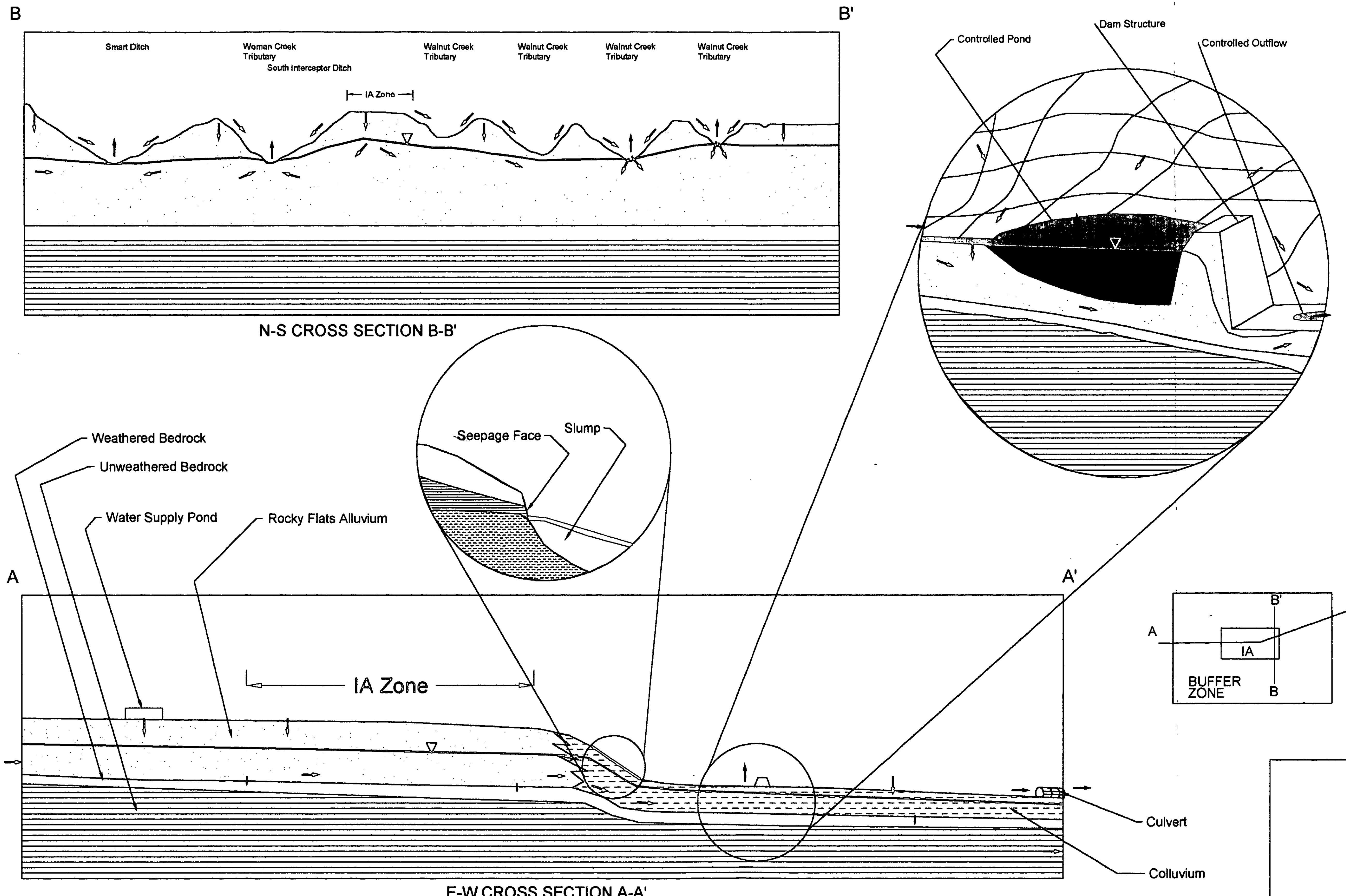
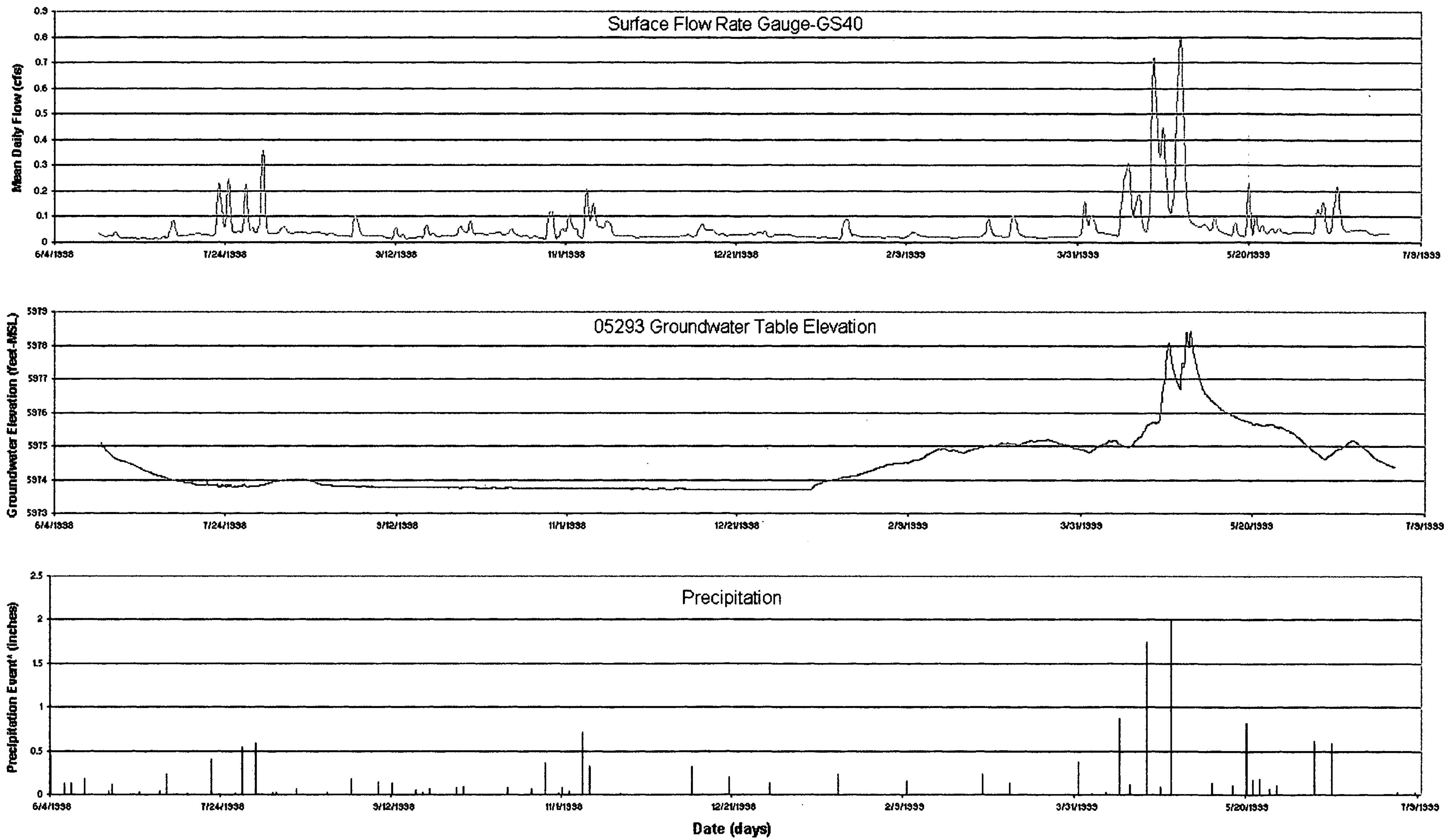


Figure 2-3
Generalized Cross-Sections

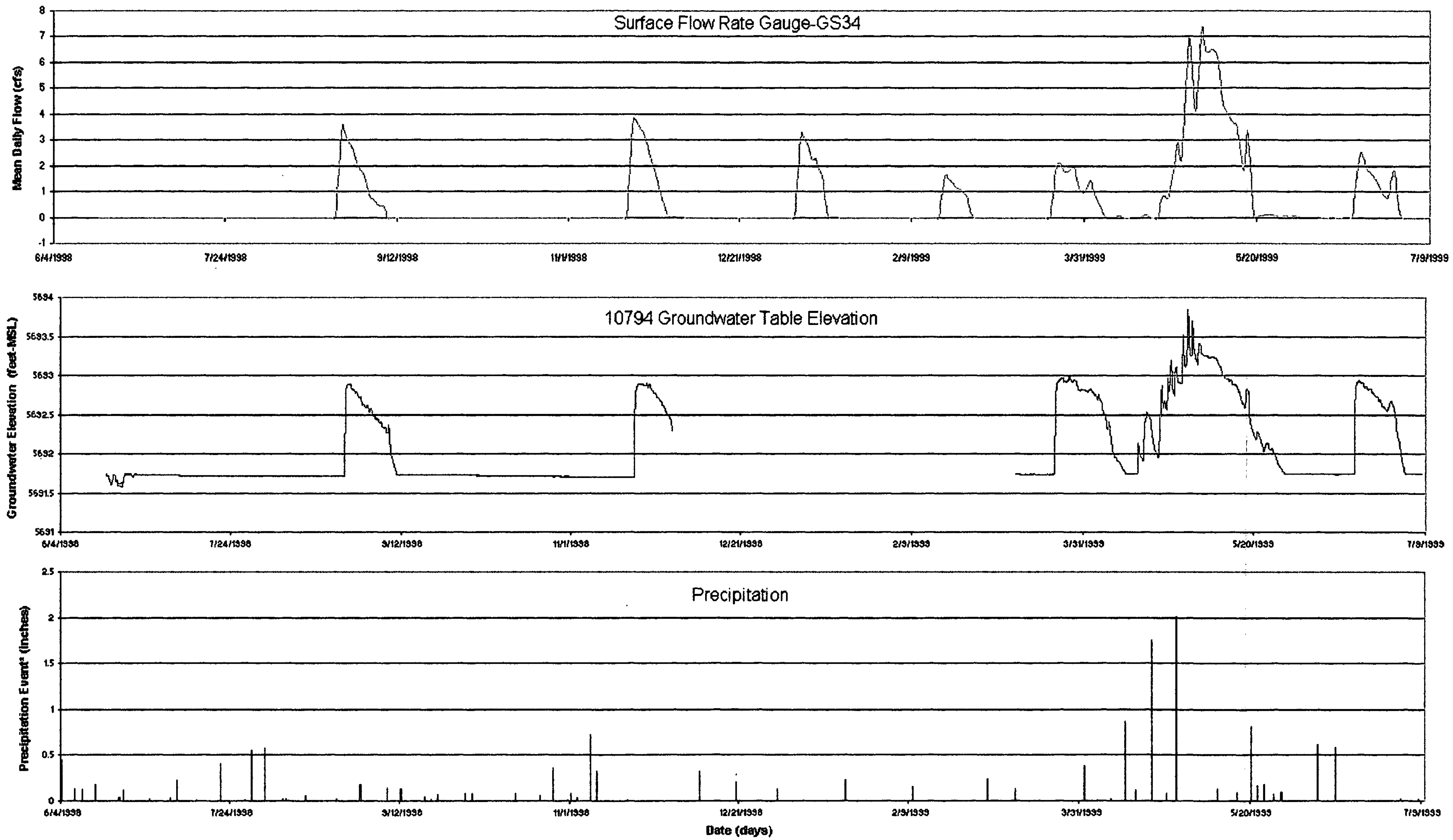
29



*Note: Precipitation amounts are per event, based on a 24-hour period.
Therefore, consecutive day's rainfall may be combined into one event total.

Figure 2-4
Response to precipitation events at GS40 and 05293

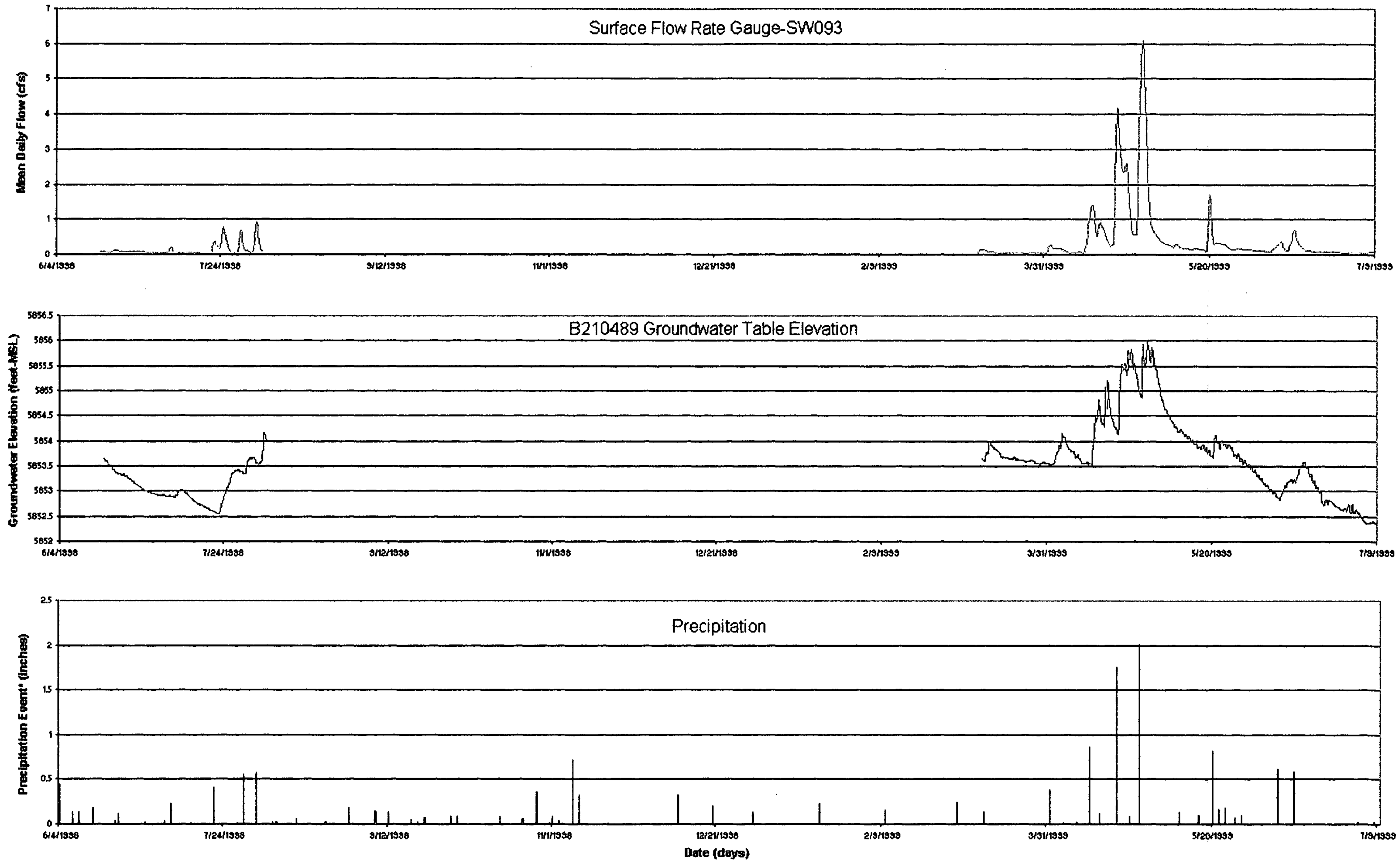
30



*Note: Precipitation amounts are per event, based on a 24-hour period.
Therefore, consecutive day's rainfall may be combined into one event total.

Figure 2-6
Response to precipitation events at GS34 and 10794

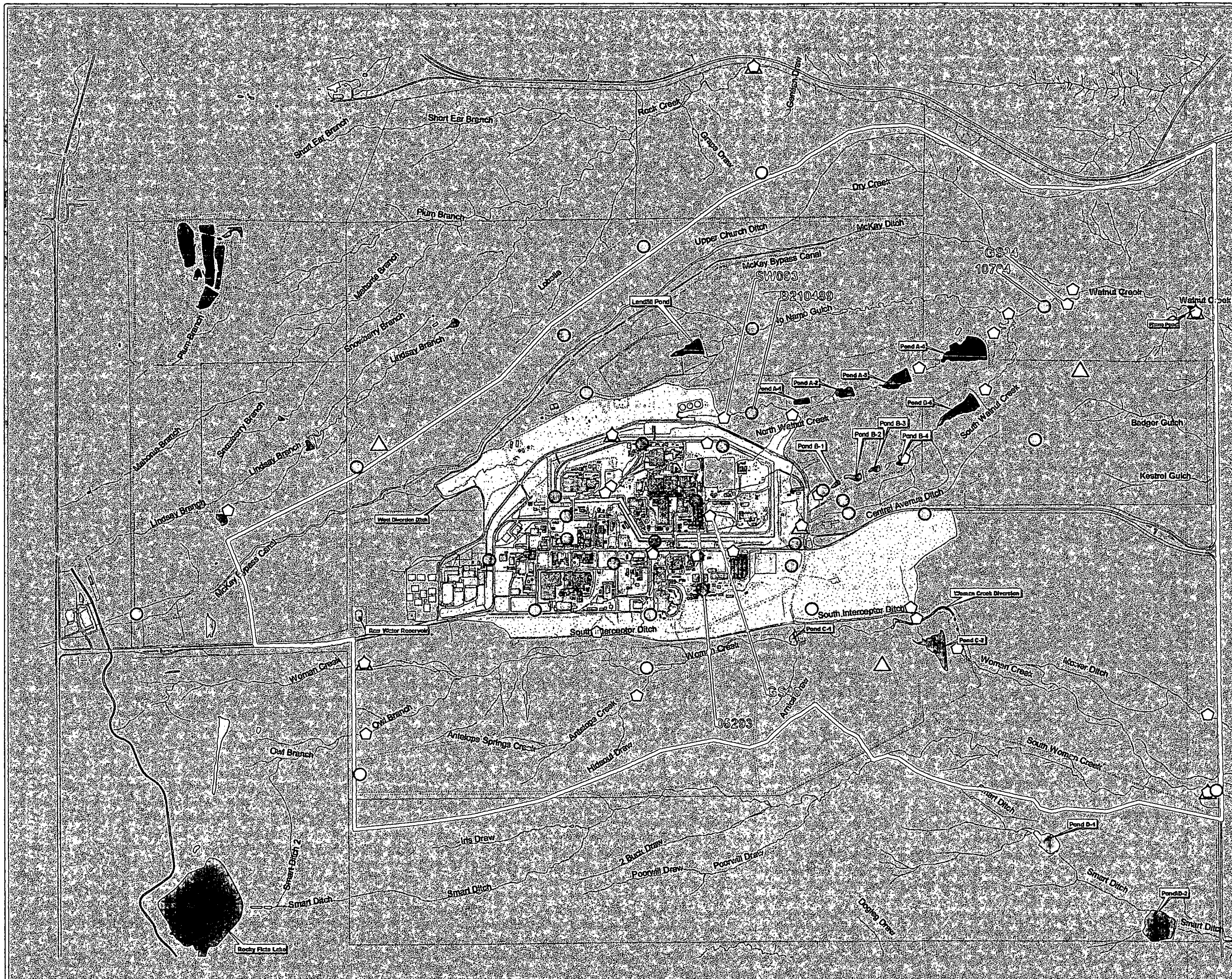
32



*Note: Precipitation amounts are per event, based on a 24-hour period.
Therefore, consecutive day's rainfall may be combined into one event total.

Figure 2-5
Response to precipitation events at SW093 and B210489

31



○ Continuous Groundwater Monitoring Wells

⬠ Surface Water Flow Gages

△ Precipitation Stations

Buildings/Structures

Surface Ponds

Approximate SWWB Model Boundary

Streams gssedits.shp

Dirt Roads (9/99)

Paved Roads (9/99)

Major IA Drainages

GS10

SW027

SW091

SW093

Fences (9/99)

Note: Surface Gauge and Continuous Groundwater Monitoring well pairs shown refer to Figures 2-4, 2-5 & 2-6.

N

1000 0 1000 2000 Feet

Rocky Flats Environmental Technology Site
(Site Wide Water Balance Project)
August 2000

Figure 2-9
Major IA Drainage
Subdivisions and
Site-Wide Gauges

38

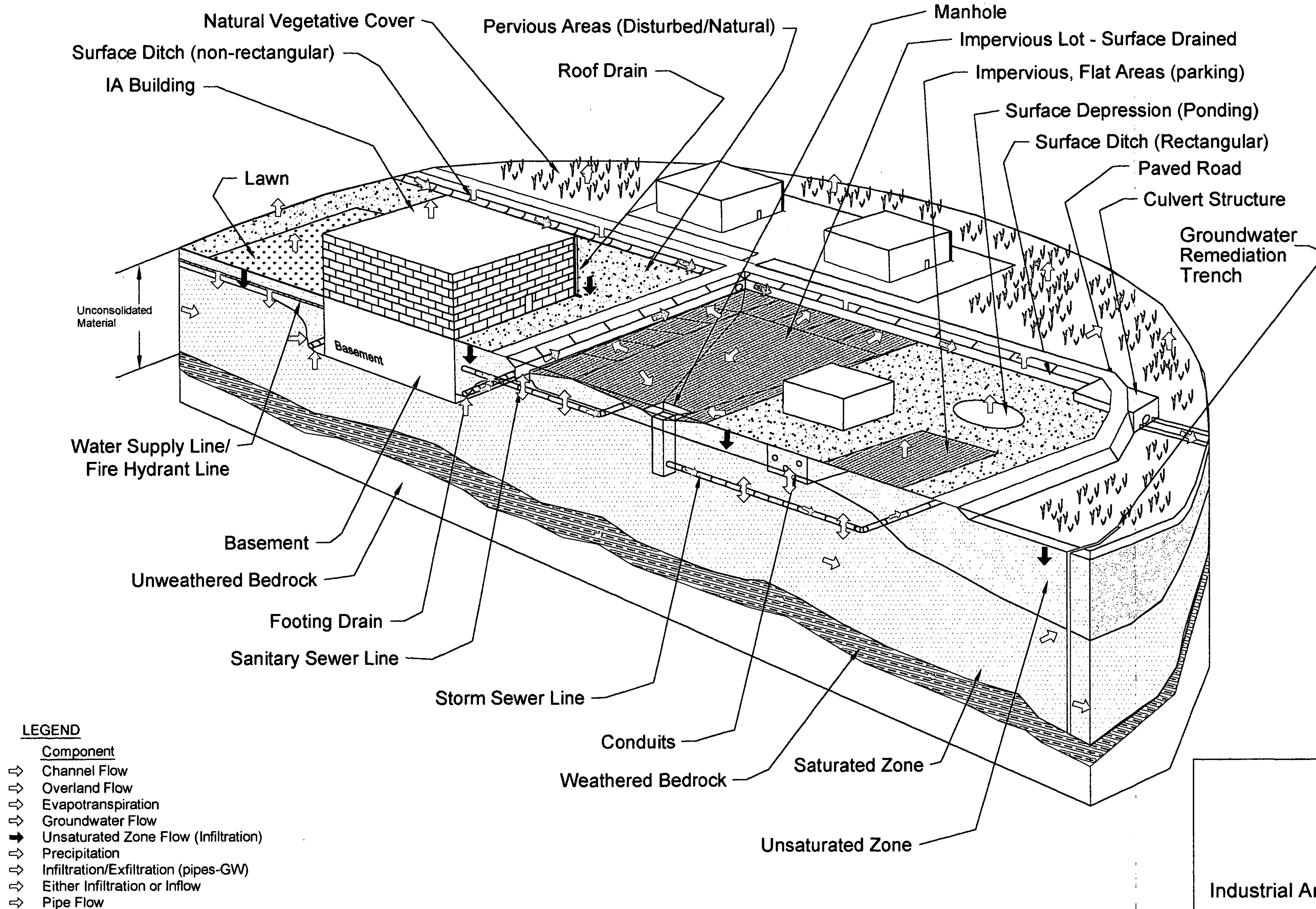


Figure 2-10
Industrial Area Conceptual Model
Flow Components

41

Table 3-2
Model input parameters

Input variables	RFETS source	Comments
Groundwater		
Geologic structure		
Hydrostratigraphic unit layer bottom elevations	RMRS database	Existing Arcview coverage will be modified with current data.
Lenses	OU2 Groundwater Flow Modeling Report	
Hydraulic properties		
Horizontal hydraulic conductivity distribution/values	RMRS database	Analysis is required since this is likely the most important variable with greatest range of uncertainty. Calibration parameter.
Vertictal hydraulic conductivity distribution/values	same	Same
Specific storage - confined conditions	same	Same
Specific yield - unconfined conditions	same	Same
Hydrologic parameters		
Depth to water (surficial deposits)	RMRS database	Database (defines unsaturated zone)
Potentiometric surface (initial conditions)	RMRS database	Database (interpreted spatial distribution)
Engineered components		
Storm sewer lines (distribution, elevations, cross-sections, estimated leakage)*	Engineering reports, existing RFETSGIS	Data not entirely complete. Relies heavily on what is available.
Sanitary sewer lines	same	same
Footing drains	same	same
Pressurized water supply pipes	same	same
Utility conduits	same	same
Remediation system (engineering structure/flow rates)	*same, quarterly monitoring* reports	Part available in current GIS, other details available in CAD format.
Surface water		
Overland flow		
Surface topography	RMRS Arcview	Existing 2' contours can be used for DEM
Friction factor - Mannings	WEPP Modeling Report	Can be estimated from former modeling studies
Detention storage	SW group	Estimate/observations
Channel flow		
Channel cross sections	WEPP/HEC modeling	Available for most Buffer Zone, but not for IA
Friction factors - obstructions, diversions, hydraulic features	Existing model studies	Ultimately a calibration-derived parameter
Surface drains/culverts	Arcview/SW group	Mostly complete, will be updated
Upstream/downstream boundary conditions	RMRS SW database	Available from SW gauging data, or through approximation.
Pond transfers	RMRS/SW group	Available and complete
Pond cross-sectional configuration	RMRS/SW group	Available, but may not reflect current configuration (due to sedimentation buildup).
Unsaturated zone		
Soil type zonations	1995 Geologic Report	USCS soil distribution figure
Hydraulic property distributions		
Saturated hydraulic conductivity - same as saturated zone	CSU report/ASI-1993	
Saturated water content (%)	CSU report/ASI-1993	Known for certain soil types, but must be estimated otherwise (I.e., use UNSODA database)
Residual water content (%)	same	same
Effective water content (%), air entry water content (maximum achievable water content)	same	same
Capillary potential at field capacity	same	same
Capillary potential at wilting point	same	same
exponent of conductivity curve	same	same
Soil depth distributions	Soils report	
Initial moisture distributions (year?)	CSU report	Can be significant, but repeated annual simulations could produce desired affect
Meteorological data		
Precipitation		
Spatial and temporal distribution of precipitation	Met station/RMRS SW stations	Requires analysis. Very important model parameter that depends on many factors (i.e., wind direction, storm size, aspect etc.)
Snowfall precipitation distribution, depths, drifts	Met tower station	Can be calculated to an extent
Temperature (for snowmelt)	Met tower station	
Wind speed.	Met tower station	
Evapotranspiration		
Evaporation and transpiration of plant cover/plant roots		Uncertain
Spatial distribution & density of vegetation	Arcview coverage	Good coverage
LAI for each vegetation type	unavailable	Literature sources
RDF - root density function	unavailable	Literature sources
Growth curves - time series for LAI & RDF	unavailable	Literature sources
Potential evapotranspiration estimates		Must be calculated from climate data (I.e., pan evaporation). Its spatial distribution will be difficult to estimate, but may be possible.

Input parameters are based on conceptual model presented in Section 2.0 of the Work Plan
*Specific data associated with engineered components are the same as storm sewer specification

Rocky Flats Environmental Technology Site
(Site Wide Water Balance Project)
August 2000

Figure 1-2
Proposed Additional Monitoring Locations

SW-A-004099